UNCLASSIFIED

AD NUMBER

AD906699

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; NOV 1972. Other requests shall be referred to Army Mobility Research and Development Lab., Fort Eustis, VA.

AUTHORITY

USAAMRDL ltr, 30 Mar 1984

THIS PAGE IS UNCLASSIFIED

AD906699

AD

USAAMRDL TECHNICAL REPORT 72-52

INVESTIGATION AND EVALUATION OF NONFLAMMABLE, FIRE-RETARDANT MATERIALS

By

S. Atallah

H. Buccigross

November 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-71-C-0042

ARTHUR D. LITTLE, INC.

CAMBRIDGE, MASSACHUSETTS

DISCLAIMERS

DISPOSITION INSTRUCTIONS

DEPARTMENT OF THE ARMY
U. S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by Arthur D. Little, Inc., under the terms of Contract DAAJ02-71-C-0042. The technical monitor for this program was Mr. H. W. Holland of the Safety and Survivability Division.

The purpose of this effort was to evaluate the feasibility of containing or restricting in-flight or postcrash fire in an attempt to allow the crew and passengers to escape or remain within a livable environment until the fire can be extinguished and rescue accomplished.

During program, an evaluation was conducted of currently available nonflammable, fire-retardant materials. After completion of this evaluation, the most promising of these materials were selected for application on two helicopters, which were then subjected to full-scale fire tests. This report presents the results of the evaluation of the various materials and also the preparation for and outcome of the full-scale fire tests.

The conclusions and recommendations contained in this report are concurred in by this Directorate.

Project 1F162203A529
Contract DAAJ02-71-C-0042
USAAMRDL Technical Report 72-52
November 1972

INVESTIGATION AND EVALUATION OF NONFLAMMABLE, FIRE-RETARDANT MATERIALS

Final Report

ADL-73588

By

S. Atallah
H. Buccigross

Prepared by

Arthur D. Little, Inc.
Cambridge, Massachusetts

for

EUSTIS DIRECTORATE
U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

ABSTRACT

The objective of this study was to evaluate the feasibility of containing or restricting in-flight or postcrash helicopter fires to allow the crew and passengers to escape or remain within a livable environment until the fire could be extinguished or the burning fuel consumed.

A comprehensive survey was made of present materials technology. A number of materials and composites were selected and tested in a specially designed furnace capable of providing a thermal flux equivalent to that encountered in JP-4 fires. Final candidate wall systems were compared for protection effectiveness, cost and weight penalty. Various combinations of isocyanurate foams, sodium silicate hydrate panels, a mineral insulation, and intumescent mastic paints were then applied to the walls of two crash-damaged helicopters (UH-1D and CH-47) and exposed to full-scale fires simulating in-flight and postcrash fires. The helicopters were fully instrumented to measure temperature, heat flux, smoke density, and toxic gases.

The results of the in-flight simulation tests indicated that it should be possible to protect the habitable compartment against a fire occurring in an adjacent compartment resulting from a fuel or hydraulic oil line leak. Sodium silicate hydrate panels placed on the fire side appeared to give the best performance.

Interior temperature and heat fluxes were above tolerable levels for humans during the postcrash fire tests in both helicopters. Smoke and particulates were also judged to be too high for human tolerance. Penetrations in the CH-47 walls occurred where isocyanurate foam could not be applied because of the presence of wiring, air ducts and hydraulic oil tubes.

The UH-1D walls did not lend themselves to foaming because of the absence of ribs and formers. The sodium silicate hydrate panels used to protect the interior walls partially collapsed because of the absence of structural support.

It was concluded that total wall protection of existing helicopters against postcrash fires is not feasible and should not be pursued any further because of cost, unreliability, and lack of assurance that the walls will maintain their integrity in a crash.

FOREWORD

This study was conducted by Arthur D. Little, Inc., under Contract DAAJ02-71-C-0042, Project 1F162203A529, with the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

The authors wish to acknowledge the valuable assistance provided at Arthur D. Little, Inc., by J. Oberholtzer and J. Valentine (toxic product analysis), R. Lindstrom (material selection), A. Camus (instrumentation), J. Hagopian (fire tests), and H. Survilas (photographer). In addition, the authors are grateful to the manufacturers who provided free samples of their materials to be tested and evaluated, and to the Fire Department of Laurence G. Hanscom Air Force Base for allowing the use of its site for the large-scale fire tests and for providing valuable standby assistance.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page
42	Temperatures Recorded in the UH-1D Cabin During the Postcrash Fire Test	66
43	Temperatures Recorded within the UH-1D Cabin During the Postcrash Fire Test	67
44	Temperatures Recorded by Thermocouples Outside the UH-1D Cabin	68
45	Total Heat Flux Measured by Brass Sphere Calorimeter in the UH-1D Postcrash Fire Test	69
46	Light Transmission in the UH-1D Cabin During the Postcrash Fire Test	72
47	Upwind Side of UH-1D After Postcrash Fire Test	73
48	Lee Side of UH-1D After Test Showing Absence of Aluminum Walls and Sagging Fire Plate Walls	73

LIST OF TABLES

INTRODUCTION

Although it has been possible to reduce the number of postcrash fires of U.S. Army aircraft by the construction of crashworthy fuel systems, it will be several years before these systems are installed in all U.S. Army aircraft. Even then, it is doubtful that all crash fires will be eliminated.

The crew and passengers aboard such aircraft have often survived the crash to find themselves trapped in a fire that engulfs their cabin. In other cases, localized fires in engine compartments or cargo areas have penetrated the walls of the habitable cabin to render it untenable.

Recent advances in cryogenic and high-temperature (reentry) technology have brought forth a wide variety of materials with interesting physical and chemical properties. A number of materials are now available which combine the properties of flame retardancy, mechanical strength and insulation. It would seem that one should be able to prevent postcrash or in-flight deaths from fires by the appropriate selection and application of one of these new materials to the aircraft fuselage or interior partitions. Unfortunately, flame retardancy is usually imparted to materials by the addition of chemicals which inhibit flame propagation. These chemicals, as well as the materials themselves, generate irritating smoke and toxic gaseous products when they are heated to high temperatures. The identity of the toxic gases, their concentrations, and their rates of generation are unpredictable because they are a complex function of the rate of heating and the temperatures to which the material may be exposed. Thus, the selection of a protective material for aircraft fuselages should be accompanied by realistic tests in which smoke and toxic gases are monitored.

The objective of this study was to evaluate the feasibility of containing or restricting in-flight or postcrash fires to allow the crew and passengers of a helicopter to escape or remain within a livable environment until the fire could be extinguished and rescue accomplished.

To achieve this objective, it was desired to review data on various flame-retardant materials and to select several materials that appeared to have the greatest potential for maintaining a livable environment within an aircraft exposed to in-flight or postcrash fire. The thermal properties, weight, cost and installation feasibility were to be examined, and a test procedure was to be developed to evaluate and compare the behavior and effectiveness of the selected materials (and combinations thereof) when they were applied to helicopter fuselage skin and to interior partition materials. The results of the experimental program were to be used to recommend the most promising fire-retardant material (or combination of materials) for protecting aircraft habitable compartments. Finally, UH-1D and CH-47 helicopters were to be examined to determine appropriate methods for applying the selected fire protection materials and the areas that should be protected. Two crash-damaged helicopters were then to be so protected, instrumented and subjected to full-scale simulations of in-flight and postcrash fires.

LABORATORY EVALUATION PROGRAM

The objective of the laboratory test program was to screen a large number of candidate wall materials by exposing aluminum panels protected by the test materials to a thermal flux equivalent to that encountered in a large-scale JP-4 fire. Various window materials and vent plugging techniques were also to be evaluated.

TEST FURNACE FACILITY

The desired thermal flux level (31,000-35,000 Btu/hr sq ft) was obtained in a furnace, the design of which was quite similar to NASA-Ames' T-3 Thermal Test Facility (Figure 1) but which was scaled-up so that 16 inch x 16 inch panels could be exposed. This was done to reduce end effects, particularly for thick samples. A stainless steel enclosure was constructed which was used to hold most panels in place above the horizontal furnace opening. Sketches of the test enclosure are shown in Figures 2 and 3. Figures 4 and 5 are photographs of the Arthur D. Little (ADL) furnace and the test enclosure in position. Thermocouples, gas-sampling tubes and a smoke density meter were used to evaluate conditions within the enclosure. A calibrated (NBS traceable) multichannel millivolt recorder was used to record the data.

Chromel-Alumel thermocouples were utilized to measure the enclosure air temperature and the interior surface temperature of the panel at two or three locations.

The smoke detector consisted of a light source and a photo cell. This was calibrated using standard filters having various absorption coefficients.

Gas samples were drawn either into evacuated glass sample bottles for chromotographic analysis or into Kitagawa tubes. These tubes detect the presence and measure the concentration of specific gases by the length of the chemical co[illegible] [illegible]ange in the packed tube.

The cond[illegible] .rior surface of the panel was noted visually [illegible] test through a mirror attached to an opening in the to[illegible] f the enclosure. An electric timer was started when the panel wa[illegible] placed above the furnace and stopped when burn-through was o[illegible]rved or when the test was terminated.

Tests on the [illegible] candidate materials were conducted by placing the window in a s[illegible]l frame on the furnace opening so that the flames impinged directly on the window. The time for the window to burn through was noted.

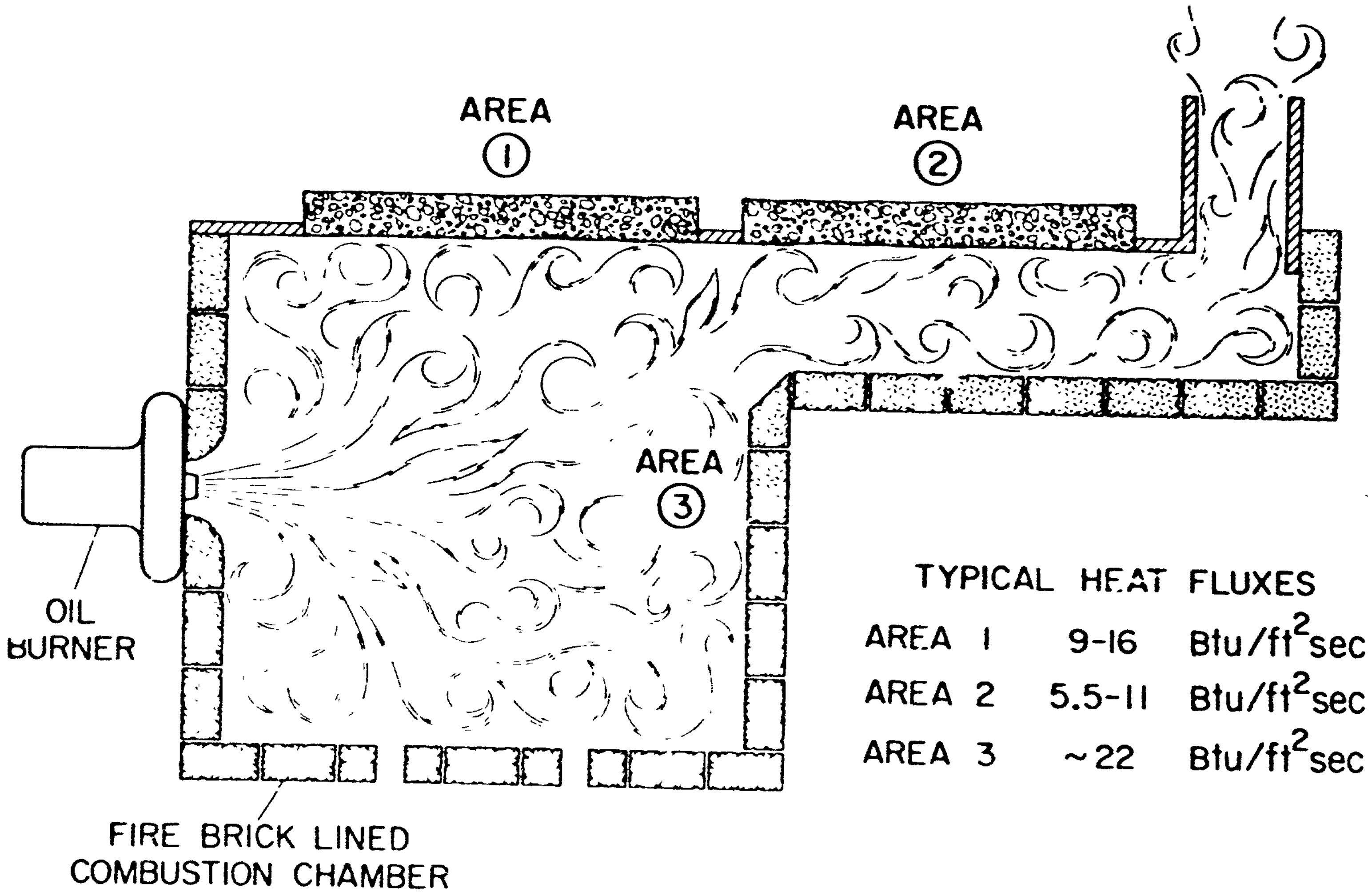


Figure 1. NASA-Ames T3 Thermal Test Facility.

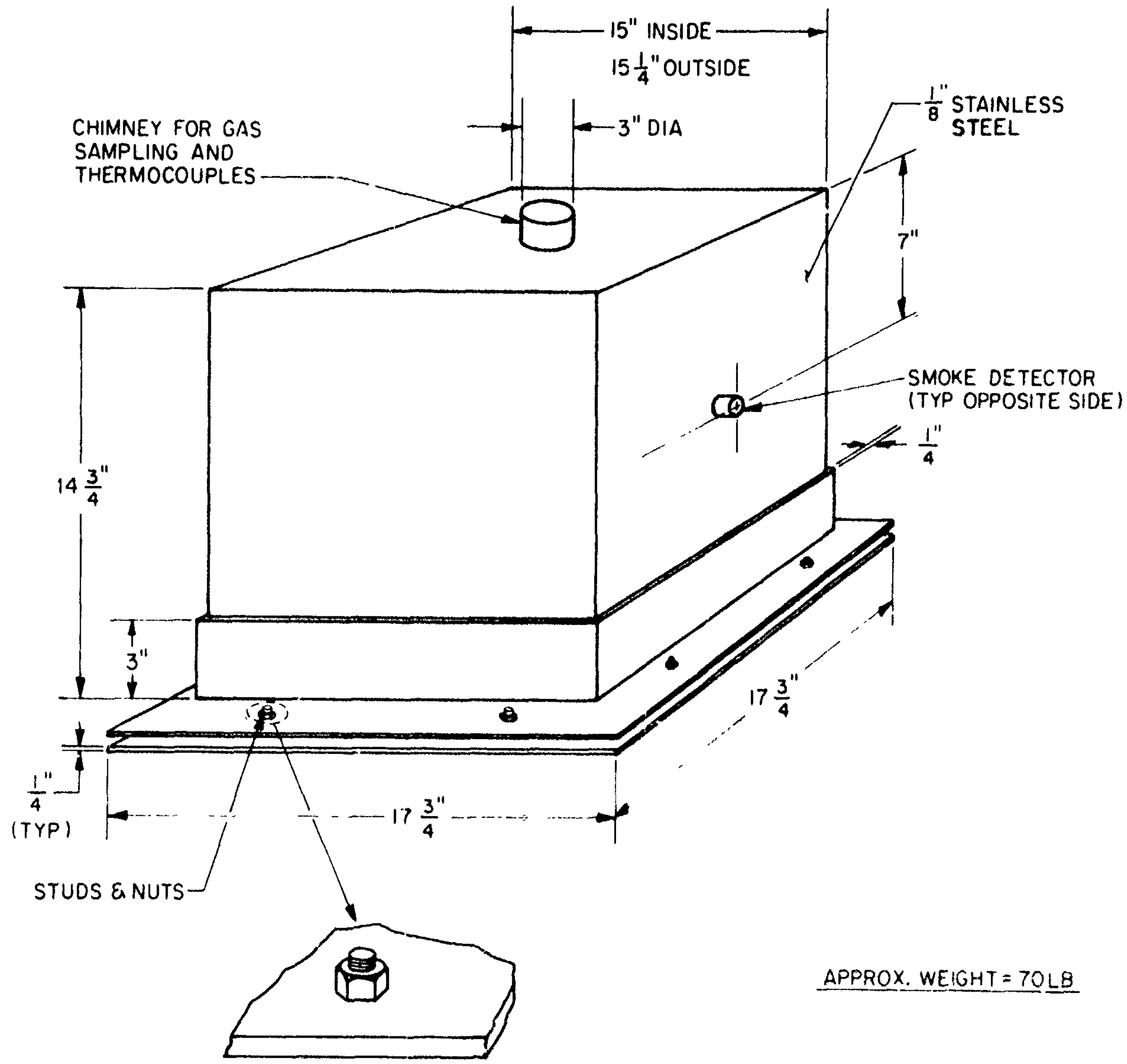


Figure 2. Helicopter Simulation Box.

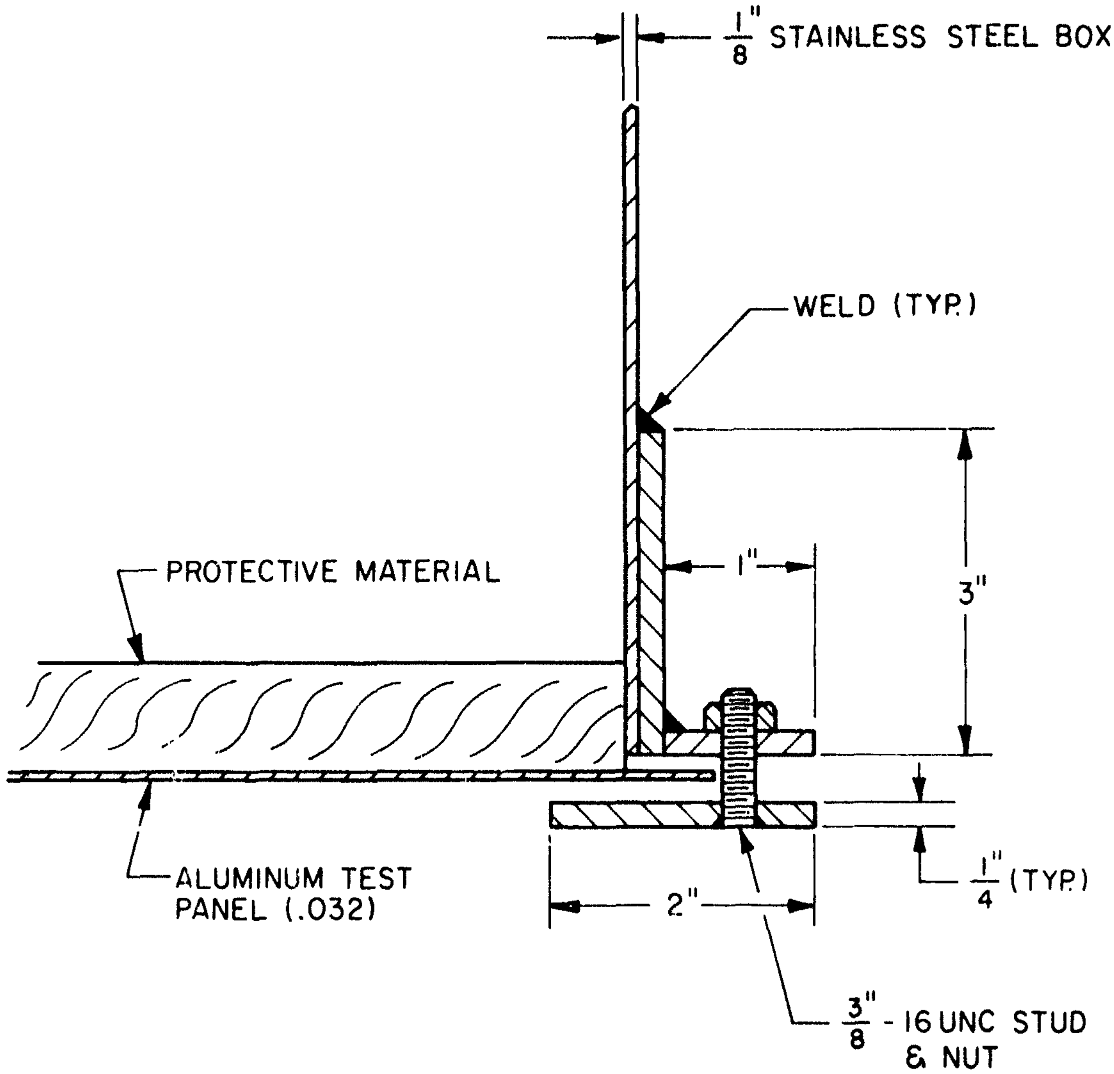


Figure 3. Details of Corner of Simulation Box.

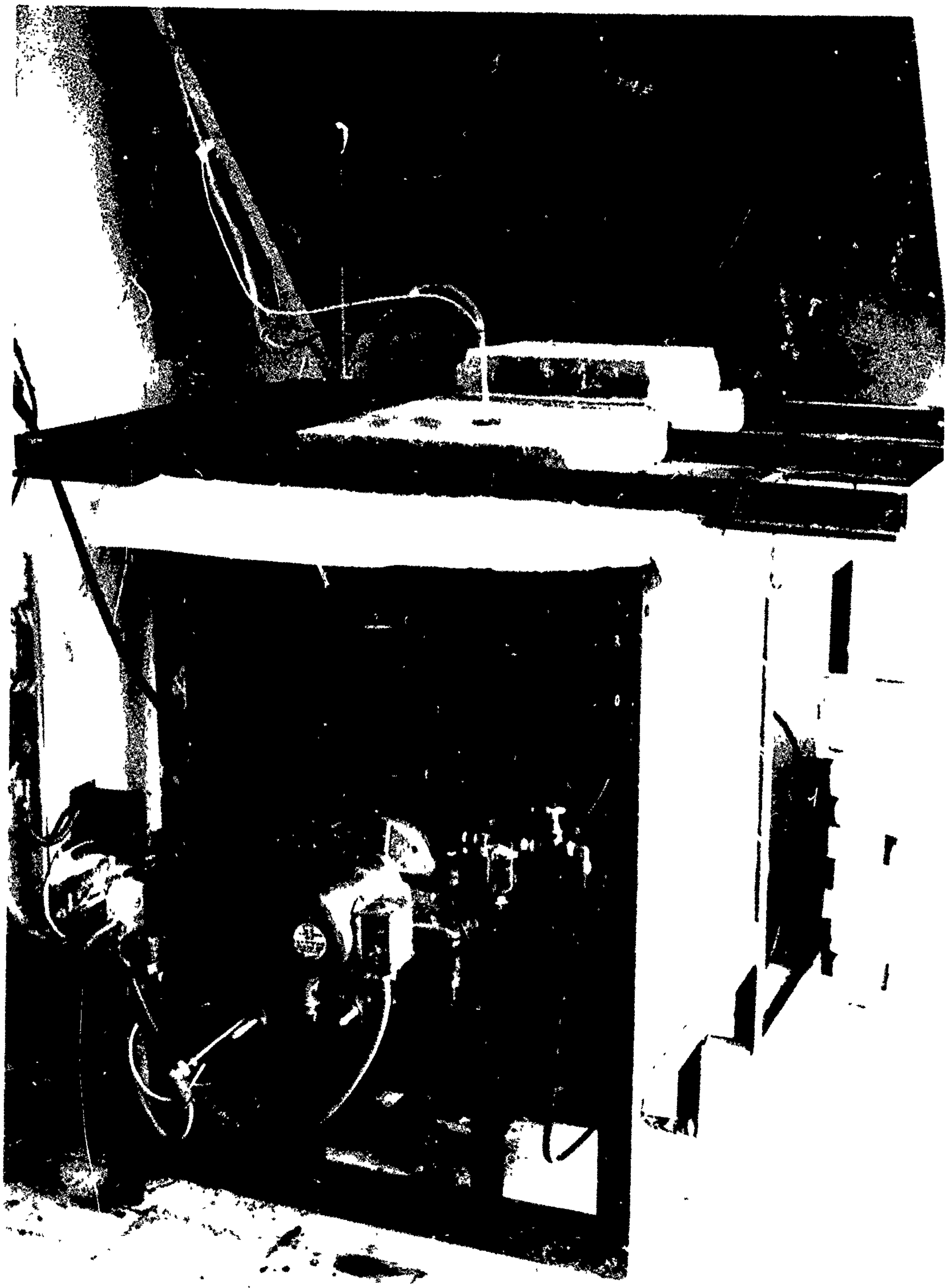


Figure 4. Overall View of the ADL Test Furnace.

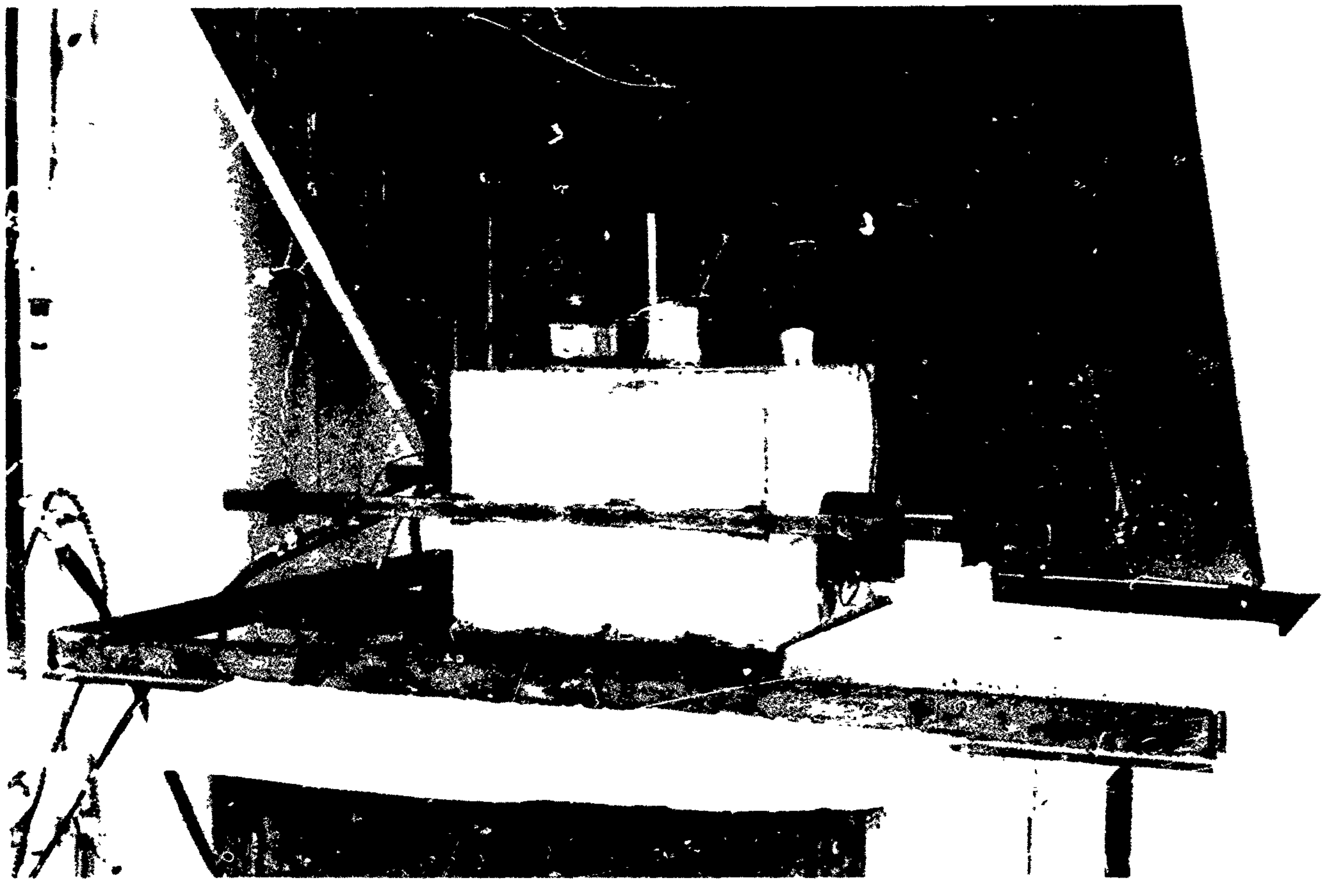


Figure 5. Test Enclosure Above Furnace Opening.

RESULTS OF LABORATORY TEST PROGRAM

The interior surface of a helicopter may be divided into four areas, each of which requires particular protection techniques. These areas consist of the exterior aluminum wall, windows, ventilation openings, and interior partitions.

Wall Areas

Much of the wall area in a helicopter is free of wiring and tubing so that fire protection materials can be placed directly on the wall without interfering with other mechanisms. However, some areas do contain hydraulic, mechanical or electrical components, and the selected insulation system should allow access to these pieces of hardware.

The materials that were evaluated for wall protection can be conveniently classified under the following categories:

- Paints and coatings
- Inorganic or mineral insulations
- Organic foams
- Fire-protecting panels and composites

Tables I, II, III, and V summarize pertinent results of tests on promising materials in these categories. Tables X, XI, XII, XIII, and XIV summarize the results for all materials tested.

Data of particular concern in the test program were the time for the flame to burn through the panel, the presence of toxic or noxious fumes in the enclosure, and the maximum temperature of the air in the enclosure.

Intumescent Paints and Coatings

A large number of intumescent paints and coatings, which are applied in thicknesses from 3 mil to 1/8-inch or more, are commercially available for fire protection. Upon heating, these materials intumesce or char, forming a protective insulating layer. Table I summarizes the furnace test results for these materials. The data indicate that no intumescent paint or coating could provide the desired fire protection. While the paints did intumesce readily and provided an insulating char, the fire gases eroded the char very quickly, exposing the bare aluminum panel to the fire. When such paints were used on the inside of a panel, they were not effective because the panel burned through and the char could not support itself. Furthermore, most of them produced noxious fumes in the enclosure. There is no apparent difference in the performance of the very expensive

TABLE 1. FURNACE TEST RESULTS FOR PAINTS AND COATINGS

System	Mfr.	Weight (lb/ft^2)	Approx. Cost Materials ($\$/100\ ft^2$)	Test Data: Exposure Time (min:sec)	Test Data: Failure	Test Data: Maximum Cabin Temp (°C)	Remarks
Albi Clad Mastic 89X (75 mil)	1	.20	32.50	1:36*	Yes	98	Char too fragile
Albi 107X, Albi 144 (40 mil)	1	.08	4.00	2:09*	Yes	108	Char too fragile
Firehold 10	2	.05	3.50	2:23*	Yes	132	Char too fragile
Flamarest (10 mil)	3	.08	127.00	1:32*	Yes	79	Char too fragile
Larodyne (1/8") (Coating on fire side)	4	.47	400.00	11:39†	Yes	197	Inconsistent results, high cost
Larodyne (1/4") (Coating on inside)	4	.95	800.00	3:30	Yes	59	Ammonia odor present, high cost
Laticote (.040") (Coating on outside)	4	.25	135.00	0:54	Yes	103	Irritating fumes, cracked, allowing flame penetration
Laticote (.020") (Coating on inside)	4	.13	70.00	2:54	Yes	132	Thick acrid smoke

1. Albi Manufacturing Dept., Cities Service Co.
2. Cheesman Elliot Company
3. Avco Corporation
4. North-American Rockwell, Space Division

* Average values of several tests.
† Maximum of several tests.

paints or the less expensive types, although there are claimed differences in weatherability and stability. The one coating that appeared to be potentially useful, North American Rockwell's Larodyne, was applied in 1/8-inch thickness to the aluminum panel and the Larodyne side of the panel was exposed to the fire. Although it took 11 min 39 sec for the panel to burn through the first test, this exceptional performance could not be duplicated. Subsequent panels did not perform as well because the char crumbled quickly. It appeared that if Larodyne is applied over large areas, stresses could develop during fire exposure which would fracture the coating and allow the rapid penetration of fire. Furthermore, Larodyne at present does not pass military specifications for exterior coatings and is fairly expensive.

Inorganic Insulations

Certain high-temperature inorganic (mineral) insulations are commercially available which have the potential of affording protection to the occupants of the helicopter without generating any toxic gases.

Two materials from Johns-Manville called Dynaflex and Microquartz were evaluated. Both of these materials afford good fire protection. However, being structurally weak (similar to fiberglass blankets), they need to be held in place and they offer little aid in filling cracks, etc. In combination with other materials, they proved to be quite useful. Table II describes the results of tests on Dynaflex and Microquartz felt panels.

An interesting fire protective panel developed by Badische Anilin & Soda-Fabrik (BASF) called Brandschutzplatte (fire plate) was evaluated. This is a 1/16-inch-thick fiberglass reinforced sodium silicate hydrate. When heated, the water of hydration was driven out, expanding the panel to 1/2-inch thickness. This panel provided excellent protection when tested on the furnace. After 7 minutes, the air temperature on the opposite side of the enclosure was only 40°C and after 12 minutes of exposure, there was no burnthrough of the fire plate (see Table II).

Organic Foams

A variety of fire-retardant organic foams, particularly polyurethane and polyisocyanurate foams, are available for foaming in place as well as in prefoamed panel form. A large number of organic foams were evaluated including Pyrell polyurethane foams from Scott, polyisocyanurate (ICU) foams SS-0011/0012 from Witco, an ICU foam from Uniroyal, and an ICU foam developed by NASA-Ames. Table III summarizes the results of these tests. Excellent fire protection (up to 10 minutes) was provided with 2 inches of NASA-Ames foam. Such foams can easily be applied by spraying or pouring and provide a convenient means of insulating an aircraft. Also, the foams are self-supporting and need little or no reinforcement to hold them in place. They appear to provide many of the desirable requirements of a wall thermal protection system.

The formulation for the NASA-Ames ICU foam is shown in Table IV.

Fire Protecting Panels and Composites

Table V shows the results for some of the most effective composites that were evaluated. Combinations which provided optimum performance consistent with low smoke and low toxic or noxious gas levels as well as economy involved the BASF fire plate in combination with either inorganic insulation or Witco or NASA-Ames polyisocyanurate (ICU) foam.

Window Areas

A number of readily available window materials were evaluated by exposing them directly to the flame in the test furnace. It was quickly determined that helicopter windows are a weak point in the structure and that the protection of windows from fire would require a full-scale development study.

Table VI summarizes pertinent results on window materials. This table also shows the results of attempts made to examine various techniques and approaches that may be used to provide adequate thermal protection. Working jointly with BASF, a very promising panel consisting of 1/8-inch acrylic - 1/8-inch transparent sodium silicate hydrate - 1/8-inch acrylic was developed which withstood the test furnace for 9 minutes. The surface temperature at the end of the test was about 75°C. Figures 6 and 7 are photographs of the two sides of the window after the 9-minute exposure to 35,000 Btu/hr sq ft heat flux.

Ventilation Openings

Since a helicopter is an air-breathing aircraft, ventilation openings are provided which draw air from the exterior. In the case of a fire, such openings could provide a path for fumes and vapors to enter the passenger compartment. Two systems which could plug the vents when they are exposed to heat were evaluated. One of these involves coating the vent interior wall or a screen inserted in the vent with an intumescent paint or mastic. When exposed to high temperatures, the coating intumesces and effectively plugs the hole. In another case, pieces of BASF fire plate were inserted in the tube in such a way that when the fire plate expanded, it completely filled the tube. Both of these approaches work quite well since the tube itself is not exposed to the erosive effects of the flame.

TABLE II. FURNACE TEST RESULTS FOR INORGANIC INSULATIONS

System	Mfr.	Weight (lb/sq ft)	Approx. Cost-Materials ($/100 sq ft)	Test Data: Exposure Time (min:sec)	Test Data: Failure	Test Data: Maximum Cabin Temp. (°C)	Remarks
1" Dynaflex Felt	5	.43	120.00	10:*	No	117	No degradation. No fumes or smoke. Excellent fire barrier - good insulation
1" Microquartz	5	.50	384.00	Not tested alone			See Table XII
Fire Plate	6	.50-.60	75.00	10:*	No	95	Excellent fire barrier. Slight epoxy odor. No noxious fumes

5. Johns-Manville Corporation
6. Badische Anilin & Soda-Fabrik (BASF)

*Removed after that time.

TABLE III. FURNACE TEST RESULTS FOR ORGANIC FOAMS

System	Mfr.	Weight (lb/sq ft)	Approx. Cost-Materials ($/100 ft^2)	Test Data: Exposure Time (min:sec)	Test Data	Test Data: Maximum Cabin Temp (°C)	Remarks
Isocyanurate foam (0011/12) 2'	7	0.35	35.00	5:6	Yes	64	Variation in density possible. Promising material. Fumes in some tests but not unpleasant.
Isocyanurate foam (0011/12) 2-1/2"	7	0.48	45.00	8:29	Yes	50	Some s ke early in test clears away quickly. Very good insulation.
NASA-Ames ICU foam - 2"	ADL	0.38	30.00	10:0	No	-	Very promising. Low smoke and fumes. Very good insulation. Forms stable char.
2 Pyrell foam - 1"	8	0.47	35.00	2:51	Yes	88	Noxious fumes.
4 Pyrell foam - 1"	8	0.84	68.00	4:39	Yes	127	Noxious fumes
ICU foam	9	0.33	50.00	2:36	Yes	50	Thick acrid smoke.

7. Witco Chemical Corporation
8. Scott Paper Company
9. Uniroyal Corporation

† Representative tests.

TABLE IV. NASA-AMES ICU FOAM FORMULATION

Components	Parts by Weight	
Niax Polyol 34-45*	100	Mixture A
Potassium Fluoroborate	52	Mixture A
Zinc Oxide	52	Mixture A
Freon 11**	100	Mixture B
DMP-30†	70	Mixture B
Mondur M.R.††	400	Mixture C
Silicone Fluid L-5340*	8	Mixture C

Mixture A is milled to 5 N.S. fineness then mixed with B. Foaming occurs when A-B mixture is added to C.

* Union Carbide Corporation

** E. I. duPont de Nemours & Co. (Inc.)

† Rohm & Haas Corporation

†† Mobay Chemical Corporation

TABLE V. FURNACE TEST RESULTS OF COMBINATIONS OF MATERIALS

System	Mfr.	Weight (lb/sq ft)	Approx. Cost-Materials ($/100 sq ft)	Test Data: Exposure Time (min:sec)	Test Data: Failure	Test Data: Maximum Cabin Temp(°C)	Remarks
1" Dynaflex Felt, Fire Plate	5,6	0.85	19[illegible].00	7:00	No	64 (52 @ 5 min)	No smoke or fumes. Good system.
2" Dyanflex Felt, Fire Plate	5,6	1.35	315.00	10:00	No	81 (57 @ 5 min)	No smoke or fumes. Good system.
1" NASA-Ames Foam, 1" Dynaflex, Fire Plate	ADL,5,6	1.13	210.00	10:00	No	-	Lower heat transfer than above.
1" NASA-Ames ICU Foam, Fire Plate	ADL,6	0.70	90.00	[illegible]	No	91 (35 @ 5 min)	Excellent system. No smoke or fumes. Low heat transfer.
1-1/2" NASA-Ames ICU Foam, Fire Plate	6	0.80	100.00	12:00	No	57	Excellent system. No smoke or fumes. Low heat transfer.
2" Witco ICU Foam, Fire Plate	7,6	0.90	105.00	9:00	No	64 (35 @ 5 min)	Not quite as good overall as above.
2" NASA-Ames ICU Foam, Fiberglass, Epoxy Surface	ADL	.50	65.00	10:00	NO	64	Surface blackened at [illegible] min; some fumes from epoxy.
2" Witco ICU Foam, Fiberglass, Epoxy Surface	7	.40	70.00	3:00	Yes	48	Insufficient protection w/o fire plate

TABLE VI. FURNACE TEST RESULTS ON WINDOW MATERIALS

Material Description	Burnthrough Time (Min:Sec)
Plexiglas GM, 1/8" (Rohm and Haas)	1:08,0:54
Plexiglas SE-3, 1/8"	0:48
Plexiglas GM, 1/4"	1:48
Plexiglas GM, 1/2"	2:48
Plexiglas SE-3, 1/2"	2:57
Plexiglas GM, 3/4"	5:38
Abcite-coated Lucite 1/8" (duPont)	1:12
Plexiglas GM, 1/8" treated with Kellogg Urethane Varnish	0:58
Plexiglas SE-3, 1/8" treated with Kellogg Urethane Varnish	0:54
Merlon Polycarbonate, 1/8" (G.E.)	0:46
Merlon Polycarbonate E-297, 1/8"	0:48
Two 1/8" Merlon Polycarbonate sheets with 1/2" air space	1:13 (1st layer fell in 0:44)
Two 1/8" Merlon Polycarbonate sheets, 1/2" air space filled with Gillette shaving foam	1:42 (1st layer fell in 1:06)
Two 1/8" Acrylic with 1/8" BASF special transparent plate between	(Removed after 9 min. No burnthrough of the top Plexiglas layer)

Interior Partitions

Since present windows are the weakest points in a helicopter, the crew cockpit would be a highly vulnerable area in a postcrash fire. Not only is the probability of the window breaking high, but the large surface area of windows exposed to the fire presents a serious fire hazard to the crew.

The only solution to this problem appeared to be an emergency door that would be accordion-folded against the ceiling of the CH-47 or the sidewalls of the UH-1D and clamped shut in case of postcrash fire after the crew had climbed into the passenger compartment. Panels consisting of an aluminum sheet (.03-inch thick) on the cockpit side, a 1-inch layer of Dynaflex and 1/16-inch BASF fire plate on the passenger compartment side provided adequate protection when tested on the furnace.

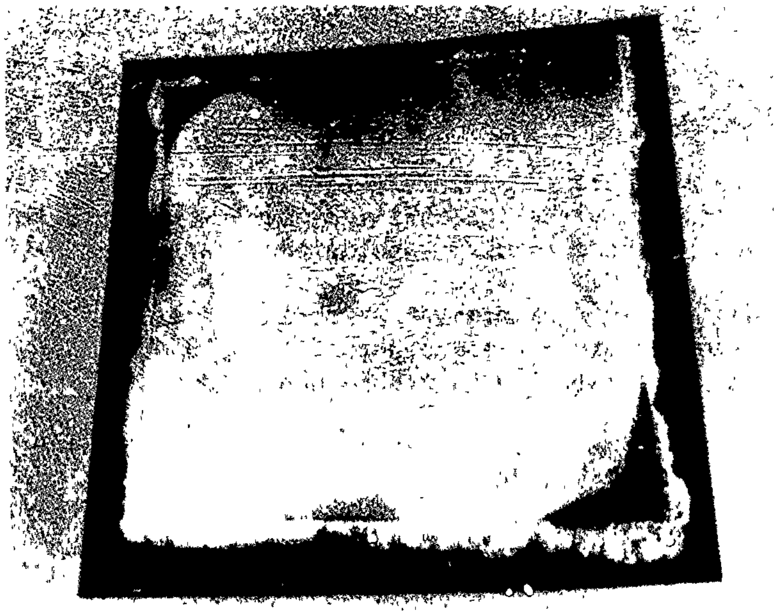


Figure 6. Photograph of Interior Plexiglas of Window After 9 Minutes of Fire Exposure.

Figure 7. Photograph of Side Exposed to Fire (Exterior Plexiglas Layer Had Been Burnt).

SELECTION AND APPLICATION OF PROTECTIVE WALLS

SELECTION CRITERIA

In selecting the most promising wall materials for the protection of the habitable compartments of helicopters against in-flight or postcrash fires, the following factors were considered:

- The wall system must provide sufficient thermal insulation to prevent the penetration of heat from the fire into the habitable compartment.
- The wall must maintain its structural integrity after aluminum skin failure.
- The materials employed should generate a minimum of toxic or irritating gases and smoke in the cabin when heated by the fire.
- The materials must be easy to apply to the walls of the helicopter and must be easy to maintain and repair.
- The materials used must be relatively light and inexpensive.
- The wall system should provide access to wiring and tubing along the walls and to other service compartments.
- If applied to the helicopter exterior, the system must pass certain military specifications relating to weatherability and erosion.

The results of the furnace test program indicated that protective paints and coatings applied to the exterior of a helicopter generally performed poorly. The only promising one (Larodyne) could not be applied in place, was relatively expensive, did not show reliable performance, and does not pass military specifications for exterior coatings.

By using an interior protective system, one generally expects the exterior aluminum skin to be sacrificed during the fire. This is particularly important if the protective materials generate toxic or irritating products. The absence of the skin allows these gases to propagate into the fire rather than into the cabin.

The test program showed that a number of composite material systems may be used for interior wall protection. Only those offering the optimum combination of desirable qualities were selected. Table VII identifies the basic composite wall systems used and their cost and weight penalty.

As indicated, helicopter windows are presently one of the weakest points in a helicopter crash fire. Current materials technology does not offer a better replacement for the 1/8-inch Plexiglas window presently used. One could increase the life of the helicopter windows significantly by increasing their thickness. Indeed, the test program showed that a 3/4-inch thick Plexiglas window appears to provide the necessary protection required during a postcrash fire. But the weight penalty would be high, particularly on the UH-1D where the window surface area is very large in comparison with the total wall area. Although this study was not intended as a developmental program for helicopter windows, tests on the simple approaches to window design that were considered showed that one should be able to design a lightweight window system from existing materials that is capable of providing the necessary fire protection.

COMPATIBILITY WITH THE HELICOPTER

One of the most important considerations in choosing one system over another is its compatibility with the particular helicopter to be protected. There are marked differences between the basic structures of the CH-47 and the UH-1D. The walls of the CH-47 have ribs and formers which support the aluminum skin. Furnace tests on typical sections of the CH-47 wall showed that these ribs and formers retain their integrity during the fire even though the skin melts within a few seconds. On the other hand, for the most part, the UH-1D consists of flat walls, windows, and doors, the latter consisting of a double aluminum wall. Ribs and formers are only used in the ceiling and the floor. Thus, the approach to protection was not the same for the two helicopters.

WALL SYSTEMS USED IN THE CH-47

Of the materials and composites which were evaluated, two stood out as providing the optimum combination of properties for wall protection. Both of these systems utilized BASF fire plate as interior paneling while either an inorganic insulation, such as Dynaflex, or an organic foam, such as an ICU foam, was used as additional thermal insulation in the walls behind the fire plate. The inorganic insulation blanket was used in areas containing wiring, piping, etc., where the panels might have to be removed for servicing of mechanical, hydraulic or electrical components. Where no such components were present, the ICU foam was not only easier and faster to apply than mineral insulation, but was also capable of filling small cavities and cracks and was less expensive. Laboratory tests had shown that neither the ICU foam nor the Dynaflex were likely to liberate toxic fumes into the cabin since the BASF panel provided a seal which prevented the fumes from reaching the interior.

A commercial foaming company was hired to spray the foam in place using off-the-shelf equipment. The only problem that arose during application of the foam was the settling of the pigments in the polyol portion of the mix. Installation of an agitator on the feed tank solved this problem easily.

TABLE VII. COST AND WEIGHT PENALTY OF SELECTED WALL SYSTEMS

Fire Plate/Dynaflex

Component	$/ft^2
Fire Plate (1/16")	.75
Dynaflex (2 layers-2" each)	4.80
Fasteners	.05
Joint Strip	.02
Cost	5.62

Estimated Weight, 2.27 lb/ft^2

Fire Plate/ICU Foam

Component	$/ft^2
Fire Plate (1/16")	.75
ICU Foam (4")	.60
Joint Strip	.02
Fasteners	.05
Cost	1.42

Estimated Weight, 1.31 lb/ft^2

Fire Plate/Dynaflex/ICU Foam

Component	$/ft^2
Fire Plate (1/16")	.75
ICU Foam (2")	.30
Dynaflex (2")	2.40
Joint Strip	.02
Fasteners	.05
Cost	3.52

Estimated Weight, 1.79 lb/ft^2

With the exception of the floor space, areas that were protected solely with ICU foam and fire plate were foamed up to the height of the formers. The floor space was filled to a depth of about 4 inches with foam and no fire plate was used there. Other wall areas which were to be protected with the combination of ICU foam and Dynaflex had only 1 inch or so of foam applied behind the wiring or tubing--then a layer of Dynaflex and finally fire plate. Other areas were not foamed since these were designated to be protected solely with Dynaflex. All windows were sealed with aluminum (.03 inch) and treated as part of the wall. After foaming had been completed, the foam was allowed to cure for at least 1 hour. Excess foam was then scraped to the height of the formers before application of the fire plate panels.

The fire plate paneling was attached to the formers with pop rivets Metal reinforcing strips were used to prevent the rivets from pulling through the paneling. Panels were overlapped at all joints. The use of rivets in the sealing strip restrained the panels in such a way that when heated they would intumesce to provide a tight seal. The fire plate panels were bent to conform to the curvature of the formers at the wall-to-ceiling junction. A door was constructed between the front cabin and the rear compartment. The door consisted of a layer of aluminum on the cockpit side, 1 inch of Dynaflex and a layer of fire plate on the inside.

WALL SYSTEMS IN THE UH-ID

The systems used in the CH-47 could not be utilized in the UH-1D helicopter. As previously mentioned, the UH-1D has a large window surface area. The doors consist of a double wall of aluminum, and most of the UH-1D walls lack the formers and ribs which are present in the CH-47. All the side window areas were covered with aluminum. ICU foam was then poured into the floor space to the level of the floor formers. The floor and wall areas were then covered with a layer of fire plate. An aluminum wall was installed between the cockpit and the passenger area, and it too was covered with fire plate. Certain areas of the exterior of the helicopter were covered with Albi Clad 89-X mastic, while other areas were painted with Firehold 10 intumescent paint. Some were left uncoated. These coatings were used to test the erosive effect of the postcrash fire.

UH-1D In-Flight Fire Protection System

For the tests simulating in-flight fires, two compartments in the rear of the UH-1D helicopter were used. These compartments had a common wall with the habitable compartment and were approximately 11 x 26 x 33 inches in dimension. One rear compartment was protected with 1/8-inch Albi Clad 89-X mastic. This material was believed to perform well in an enclosed area where the erosive effect of the fire would be small. The mastic was applied by brush to the bottom and sides of the compartment. A similar compartment on the opposite side of the helicopter was protected by lining its walls with BASF fire plate. The fire plate was fastened to the walls with pop rivets. No metal reinforcing strips were used in this case.

FIRE TEST PROGRAM

Four tests were conducted: two representing an in-flight fire in a compartment adjacent to the habitable compartment of the UH-1D helicopter and two representing postcrash fires engulfing the two helicopters (UH-1D and CH-47) that were provided. A general description of these tests is given below. Also given are details of the measurements made and instrumentation used. Results of these tests are discussed in Results (p. 45).

GENERAL DESCRIPTION OF TESTS

In-Flight Simulation Tests

The UH-1D helicopter appeared to be the more suitable for the conduct of these tests. The aft section had several compartments that could be used to simulate a fire due to a fuel or hydraulic oil line break. These were the first tests conducted. Not only did they provide valuable background for the conduct of the larger scale tests and for checking the instrumentation system, but they also allowed any damage to the UH-1D to be corrected before its final total engulfment test.

To simulate a fuel line break fire, JP-4 was pumped at 10 lb/min through a nozzle at the end of a copper tube into one of the aft compartments, ignited and allowed to burn for 5 minutes. The first test utilized the compartment protected with Albi Clad 89-X mastic with the top of the compartment completely open. The second test involved the fire plate lined compartment. In this case, the top of the compartment was partially covered, leaving an opening 2 inches wide along its 26-inch length.

Figure 8 shows the compartment that was protected with BASF fire plate. Figure 9 shows the fire in progress in the compartment protected with Albi mastic.

CH-47 Postcrash Fire Test

The third test involved the CH-47. The protected instrumented helicopter was transported to the test site (L. G. Hanscom Field, Bedford, Mass.) and placed in an earthen dike about 50 feet in diameter. This area was assumed to represent an average fuel spill area in a crash of a CH-47. After making the necessary connections for instrumentation, gas sampling, video-observation, interior lighting, etc., 1100 gallons of JP-4 (nearly a full load) were poured into the diked area and ignited. The dike floor was saturated with water from previous rain and was uneven. Some fuel

Figure 8. Second In-Flight Fire Simulation Compartment With Partial Cover Down.

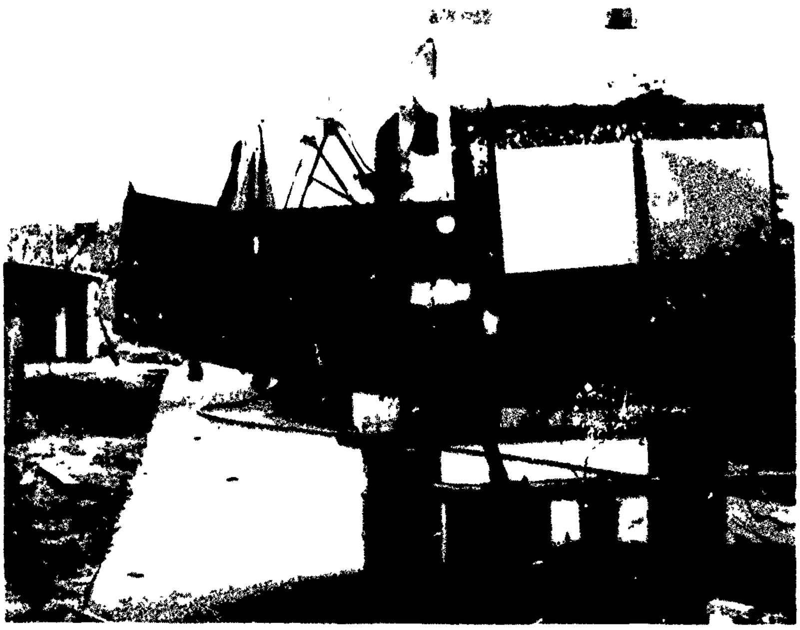


Figure 9. First In-Flight Fire Test in Progress.

was trapped underneath the helicopter. Inclement weather conditions prevailed, with rain, sleet and snow falling throughout the test period. Wind of 10-20 mph was blowing along the length of the helicopter from the cockpit toward the aft section. Figures 10-13 show the progress of the CH-47 postcrash fire.

UH-1D Postcrash Fire Test

For the final test, the protected and instrumented UH-1D helicopter was transported to L. G. Hanscom Field and placed in a 20-foot diameter earthen dike. The dike was level and saturated with previous rain water. Figures 14-17 show the progress of the UH-1D postcrash fire. Excellent weather conditions prevailed. Wind was approximately 4-6 mph and blowing across the helicopter in a left to right direction.

SAMPLING AND MEASUREMENT OF TOXIC GASES AND SMOKE

General Discussion

Although substantial increase in crew safety was anticipated by the use of the candidate fire protection systems that were evaluated in the laboratory test program, the use of the candidate systems introduced a potential hazard to the crew from exposure to toxic gases which might be generated when the protective materials were exposed to fire or when there was a partial failure of the system.

The purpose of the tests which are described in this section was to provide a semi-quantitative indication of whether or not a potentially hazardous situation might arise in an actual fire situation. The accurate assessment of toxicity in situations such as this cannot be made by chemical measurements alone. Information on the short-term (10-minute exposure) toxic hazards associated with many of the gases which might be evolved is not generally available for humans. It is also impossible to account accurately for the many synergistic effects on toxicity which can arise when a wide variety of toxic species are present, especially when compounded with thermal effects. A good assessment of toxicity in cases such as this can only be achieved through well-controlled and supervised tests involving animals. An evaluation of that magnitude was neither warranted nor desired in this initial feasibility study. For those reasons, the sampling and analytical techniques described below were designed to provide initial insight into the problem of potential toxicity and at the same time to minimize unnecessary complexity and excessive cost. Toxic gas and smoke measurements were made only in the postcrash fire simulation tests. It was assumed that toxic gases and smoke generated during in-flight fire will not affect the habitable compartment since the fire occurs in another compartment and because the doors can be opened to provide fresh air to the occupants.

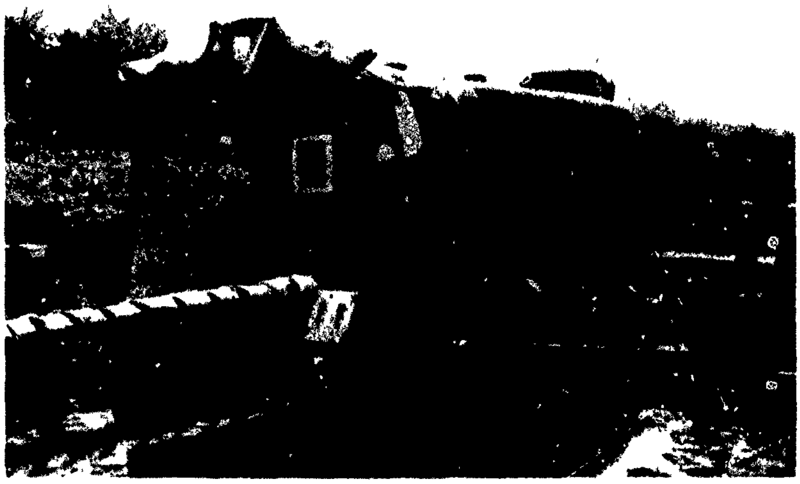


Figure 10. CH-47 Before Postcrash Fire Test.

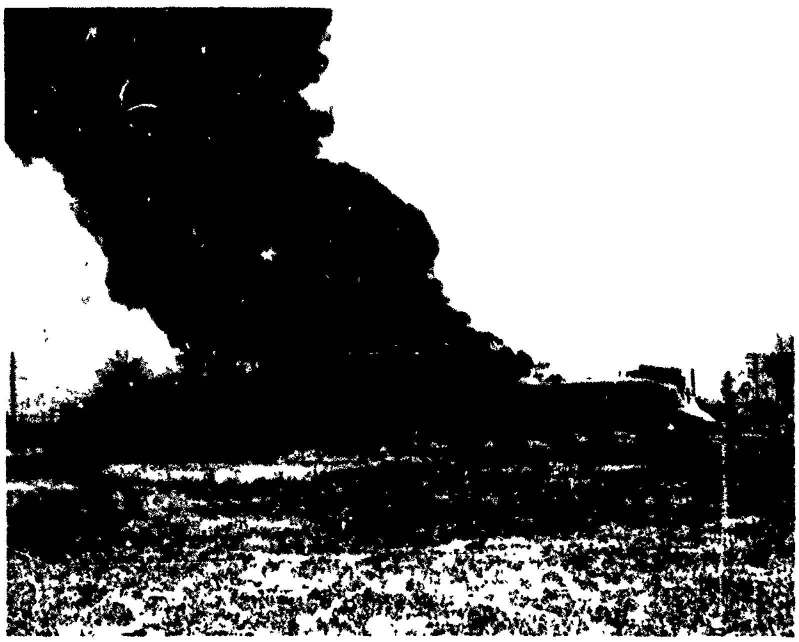


Figure 11. CH-47 Fire in Progress Soon After Ignition.

Figure 12. CH-47 Fire at Maximum Intensity.

Figure 13. CH-47 Cockpit Near Conclusion of Test.

Figure 14. UH-1D Before Postcrash Fire Test.

Figure 15. UH-1D Postcrash Fire After 30 Seconds.

Figure 16. Fully Developed UH-1D Postcrash Fire (3 minutes).

Figure 17. UH-1D Fire Near Conclusion (8 minutes).

Toxic Gases of Concern

Of primary concern were the amounts of the fire gases, carbon dioxide and carbon monoxide, which tend to build up in the cabin interior. Oxygen depletion as a result of burning or slow oxidation within the cabin was also of interest. Concentration of toxic gases which can arise from the decomposition of the insulating materials as well as from pyrolysis and combustion of fire retardants incorporated in these materials was also to be measured.

The primary toxic species which could arise from the isocyanurate (ICU) foam used in these tests were the nitrogen-containing compounds -- HCN and NH_3. Halogen-containing materials such as potassium fluoroborate and halon 113 (CCl_3F) are employed in the candidate isocyanurate foam to impart flame retardancy. When exposed to fire, these materials produced BF_3, free halogen, and hydrogen halides. Since these materials are of roughly the same toxicity, samples were taken and analyzed for the amount of fluoride, chloride and bromide ions present.

Pyrolysis of the isocyanurate foam also produced a variety of higher molecular weight, nitrogen- and oxygen-containing organic compounds of widely varying toxicity. These materials can appear as gases or as a thick smoke (condensed liquid aerosol), as was observed in certain of the earlier furnace tests. These heavier materials are produced because much of the pyrolysis to which the interior cabin is exposed will occur, at least initially, at relatively low temperatures which favor formation of heavier degradation products. Relatively higher molecular weight amines, aldehydes, ketones, acids and unsaturated hydrocarbons can be envisioned. Because of the large number of possible compounds and the uncertainty as to which compounds would indeed be formed, individual tests could not be conducted. However, in conjunction with the taking of samples for measurement of the several gases of particular interest, samples of smoke that arose were collected. These heavier molecular weight materials were simply weighed to arrive at average particular concentration over the sampling period.

Sampling Procedures

Carbon Dioxide, Carbon Monoxide, and Oxygen

Samples of these gases were taken at two points near the center of the CH-47 helicopter cabin: the first at 1 foot above the floor level, and the second at 4 feet above the floor. Two samples were taken at about the 2-1/2-foot level of the UH-1D. A gas stream for sampling carbon dioxide, carbon monoxide, and oxygen was withdrawn from each sampling point through a separate length of 1/4-inch O.D. copper tubing which extended from the cabin interior passed through an insulated service umbilical through the fire zone to a protected area about 70 feet from the fire zone. One liter grab samples were taken into a glass sampling bulb from this gas stream at 3-minute intervals during the test.

The design of the pumping and sample receiving station is shown schematically in Figure 18. A limiting orifice between the sampling bulb and vacuum pump was used to control the flow rate through each sampling line at approximately 3 liters per minute. The operation of the grab sampling system is described with respect to the operation of circuit 1. The operation of circuit 2 was identical. At the start of the test, stopcocks A and B (attached to the sampling bulb) were opened and a gas flow of 3 liters per minute from sampling point 1 was allowed to sweep through flask P. At the end of 3 minutes, the initial air that had been in flask P was completely swept out by a gas sample that was representative of the atmosphere at sampling point 1. At this time, stopcock B was closed, and, after waiting a few seconds for the pressure in flask P to equilibrate at 1 atmosphere, stopcock A was closed and stopcocks C and D opened to begin acquiring the next sample in flask Q. While the gas stream was sweeping flask Q, flask P was replaced by a new flask in preparation for the acquisition of the third gas sample, and so on.

Reactive Gases

The other gases of interest, NH_3, HCN, and the halogens and halides are more reactive and would have a strong tendency to be lost on the surfaces of long sampling lines if one attempted to withdraw a sample from the cabin to the sampling station as planned for CO_2, CO, and O_2. For this reason, gases were trapped in 25-ml midget impingers in which the reactive toxic gases of interest were absorbed into appropriate reagent solutions. The impingers, each containing 15 ml of reagent, were located in the cabin in close proximity to the sampling point. They were installed prior to the test, actuated just before the test began, and retrieved from the cabin after the test had been completed.

A set of two impingers was required for each of the two sampling points. An impinger pair along with its associated filters and vacuum service, is shown schematically in Figure 19. For collecting NH_3, and other amines and basic species, one of the two impingers was filled with 0.1M sulfuric acid. The second impinger was filled with 0.1M sodium hydroxide for trapping the acidic species: HCN, halogens, and halides. To prevent any particulates from entering the impinger and to obtain a sample of the particulates for subsequent analysis, each impinger was equipped with a dual filter assembly composed of a drying tube filled with glass wool followed by a conventional paper filter. Both filters were

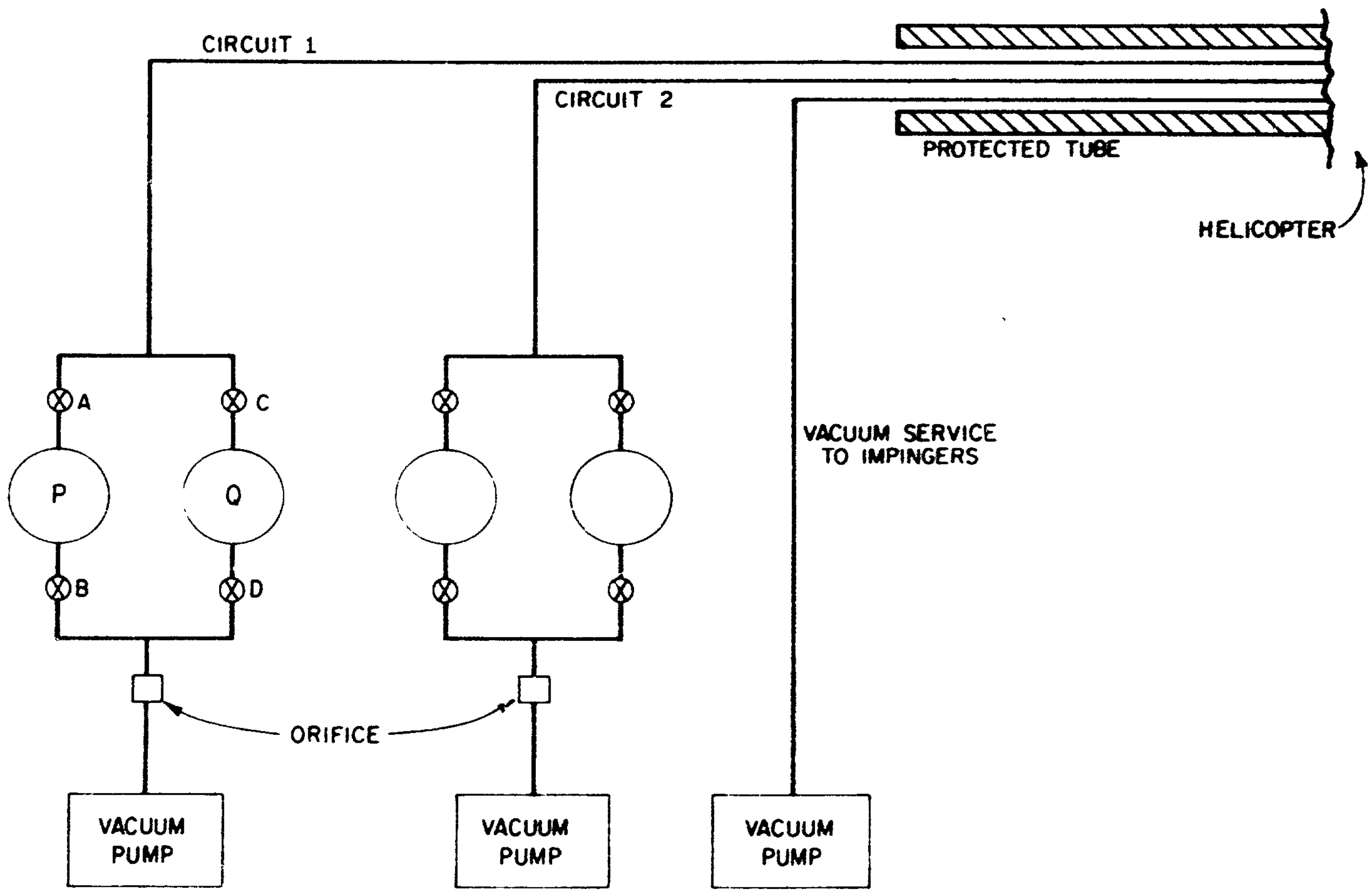


Figure 18. Exterior Sampling System for CO_2, CO, and O_2.

preweighed so that a second weighing after the test permitted an estimate of the particulate concentration in the cabin to be made. Individually calibrated orifices were installed after each impinger to control the gas flow through each impinger at a rate of 3 liters/min.

Gas Analysis Techniques

Carbon Dioxide, Carbon Monoxide, and Oxygen

These three gases were measured by temperature programmed gas/solid chromatography using columns of molecular sieve on a gas chromatograph. A helium carrier gas flow rate of about 80 ml/min was used; detection was via a thermal conductivity unit maintained at 175°C. The molecular sieve column was 2.5 feet x 0.25 inch diameter packed with 100/110 mesh 5A° molecular sieve. This column was held at 60°C for the first 6 minutes of the analysis, then heated ballistically to 170°C at a rate of about 15°/minute and finally held at 170°C until the CO_2 peak emerged.

A 3-ml sample was withdrawn from the flask containing the gas sample and injected into the chromatograph. This sample size gave a detectability for each of the three gases of about 0.05-0.1%.

Calibrations were accomplished using appropriate gas mixtures containing CO_2, CO, and O_2 in He which were procured from a commercial vendor. The composition of the calibration gases was certified by the vendor to be accurate to better than $\pm$ 5%.

Hydrogen Cyanide

The cyanide content of an aliquot of the sodium hydroxide impinger solution was measured by using the colorimetric method for cyanide as described in the Standard Method for Examination of Water (American Public Health Association, 1960). This method involves the reaction of cyanide with Chloramine-T and then with methylphenylpyrazolone to yield a blue color which is measured by spectrophotometry. For a 30-liter gas sample (3 liters per minute for about 10 minutes), this analytical method for a cyanide had a sensitivity of better than 0.1 ppm HCN in the test atmosphere.

This method was standardized using accurately prepared solutions of reagent grade sodium cyanide.

Ammonia

The ammonia analysis was performed on an aliquot of the sulfuric acid impinger solution. The measurement utilized Chloramine-T plus methylphenylpyrazolone color reagent similar to that used

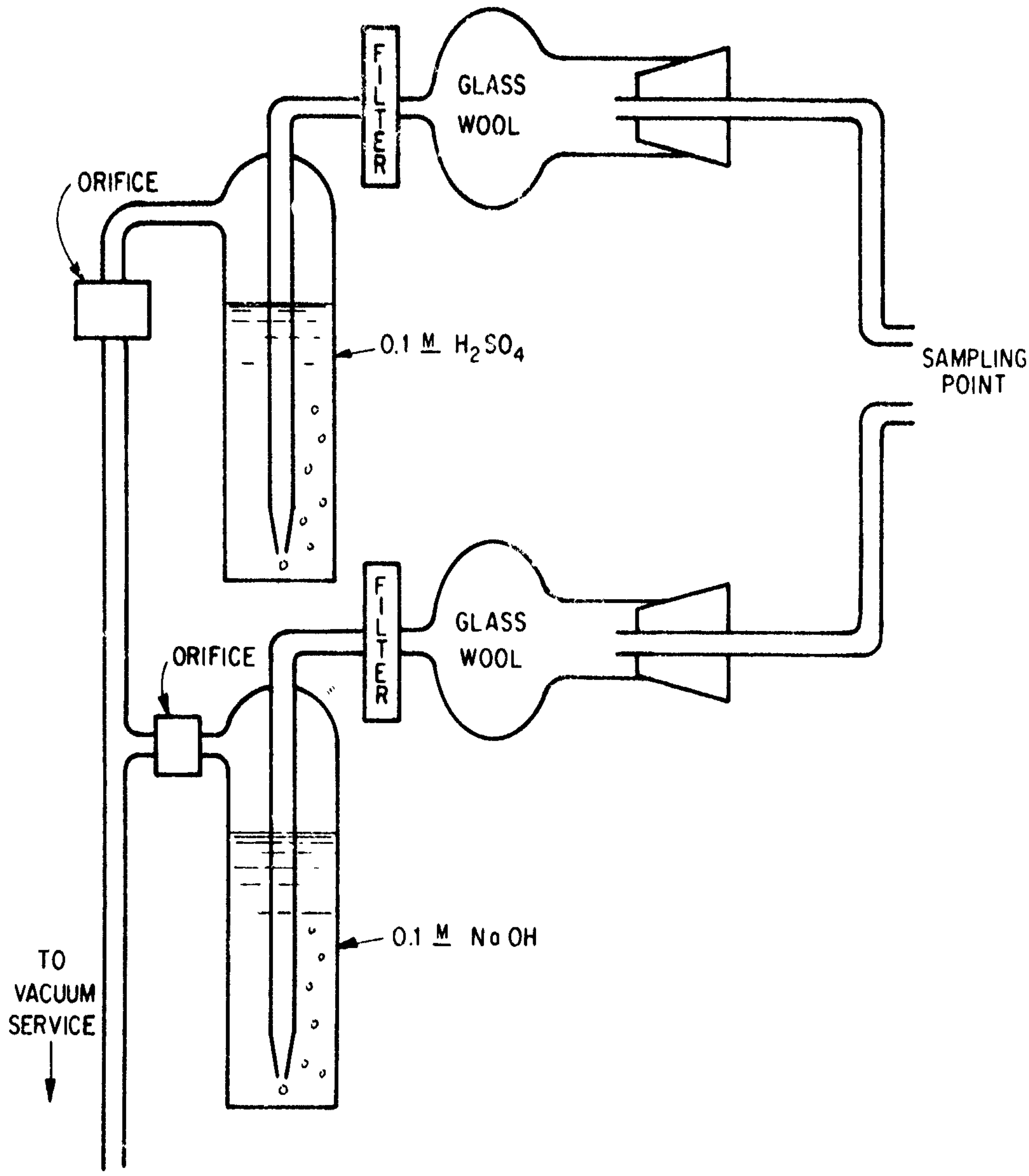


Figure 19. Interior Sampling System for Reactive Gases.

for the cyanide analysis. The procedure is described in "Colorimetric Determination of Non-Metals," D. F. Boltz, Editor, Interscience (1958). For a gas sample volume of 30 liters, this method was again sensitive to less than 0.1 ppm of ammonia in the gas sample. Standardization involved measurements of calibrated solutions of analytical reagent grade $(NH_4)_2SO_4$ in distilled water.

Fluoride Ion

The analysis of fluoride was made with a solid-state fluoride ion electrode. A 2-ml aliquot of the caustic impinger sample was pipetted into 10 ml of 15% sodium acetate solution to provide the proper pH and ionic strength. The fluoride electrode has a selectivity for fluoride over a chloride, bromide and carbonate of at least 1000. Calibrations were carried out and checked after every 5-6 samples using sodium fluoride standard solutions diluted in the same way as the samples. This technique was capable of detecting fluoride ion at less than 1 ppm and has a relative precision of approximately $\pm$ 5%.

Chloride and Bromide Ions

A silver/silver bromide electrode (prepared by electrolyzing silver wire in dilute Hbr) was used for the direct measurement of bromide ion in the NaOH impinger liquid. The selectivity of this method for bromide was 300-400 over chloride and greater than 1000 over fluoride. Only iodide and sulfide ions could interfere if present, but these were not expected. Calibration was carried out and checked after every 5-6 samples using fresh analytical standard solutions of aqueous HBr. The measurement had a relative precision of approximately $\pm$ 5%.

Chloride ion content was measured with a silver/silver chloride electrode prepared in a manner similar to the bromide electrode used above. However, prior to the chloride measurement, if bromide was present it was removed by mixing 10 ml of sample with 10 ml of 3N HNO_3, evaporating (without boiling) on a hot plate to 10 ml and then diluting to 25 ml with deionized water for subsequent measurement. This procedure had been tested on a solution containing 1.1×10^{-2} M HCl and 1.1×10^{-2} M HBr. After carrying out the bromide removal procedure, the concentrations of HX left (corrected back to the initial 10-ml sample volumes) were 1.1×10^{-2} M HCl and $< 5 \times 10^{-6}$ M HBr. This treatment should also remove iodide and sulfide which would be serious interferences if present. Calibration was performed by using fresh analytical standard solutions of aqueous HCl.

Measurement of Smoke

Smoke buildup in the cabin was monitored by two simple photometers which responded to the increasing optical density of the cabin atmosphere as smoke developed. Each photometer consisted of a light source and a photocell positioned at opposite ends of the cabins. A collimated light beam from the source was directed down the length of the center of the cabin and impinged upon a phototube detector in the receiver. The decrease in light intensity reaching the detector as a result of smoke buildup was read out as a decrease in percent transmission on a calibrated millivolt scanner recorder. For the CH-47 helicopter, two photometer systems were utilized: one positioned 1 foot above the cabin floor and the second 4 feet above the floor. The photocell was 20 feet away from the light source. Only one photometer was used in the UH-ID postcrash fire test. This was placed at the 2-foot level from the floor with the photocell 4-1/2 feet away from the light source.

The photometer systems were similar to the one used in the small-scale furnace measurements except for modifications in the transmission optics to minimize divergence of the light beam over the longer path lengths involved in these tests.

Each photometer was calibrated immediately before the test by generating a calibration curve of percent transmission versus recorder reading in millivolts. In addition to the obvious points of 0% and 100% transmission, neutral density filters were used to generate calibration points at five intermediate transmission values.

THERMAL INSTRUMENTATION

Temperature

Since the air temperature of the habitable compartment of a helicopter engulfed by flames or threatened by a fire in an adjacent compartment is of particular concern in determining its habitability, a number of chromel-alumel thermocouples were placed at carefully selected points inside each helicopter and at strategic locations on the interior walls. Other thermocouples were used to measure flame temperatures outside the helicopter or in the burning compartment. For the CH-47 postcrash fire test, thermocouples were also placed in the video camera compartment.

The distribution of the thermocouples used in the UH-1D in-flight fire tests is shown in Figure 20 for one test. In the second test, the thermocouples were placed in symmetrical positions, in the other half of the helicopter. The distributions of thermocouples in the helicopters during the postcrash simulation fires are shown in Figures 21 and 22.

Total Heat Flux

Another important factor in determining the habitability of a helicopter compartment during a fire is the total heat flux that may impinge on the human skin. A calibrated heat flux meter was located at the 6-foot level in the CH-47, facing the roof of the helicopter. Additional simple calorimeters were utilized to measure heat flux at other points. These calorimeters consisted of small blackened brass spheres of known mass. A thermocouple was imbedded in the sphere and the heat flux to the sphere at any moment was calculated from the temperature record during the fire and the equation

$$\dot{Q} = MC_p \frac{\Delta T}{\Delta \Theta} = \dot{q}A$$

where

$\dot{Q}$ = total rate of heat transfer (Btu/hr)

M = mass of the brass sphere (lb)

C_p = specific heat of brass (Btu/lb°F)

$\frac{\Delta T}{\Delta \Theta}$ = slope of the temperature time curve at a particular instant in time (°F/hr)

$\dot{q}$ = heat flux (Btu/hr sq ft)

A = area of sphere

Figures 20, 21, and 22 show the locations of these heat flux meters.

PHOTOGRAPHIC AND VIDEO COVERAGE

Exterior photographic coverage of all four tests and interior video coverage of the CH-47 postcrash fire test were carried out. Color 16-mm movie film and 35-mm slides were taken of the helicopter exteriors before, during and after each fire. The interior was also photographed before and after each fire.

A wide-angle video camera housed in a well protected enclosure was installed in the aft section of the CH-47 helicopter. A 1-inch video recorder and monitor was used to tape and monitor the sequence of events in the interior of the CH-47 during the postcrash simulation fire.

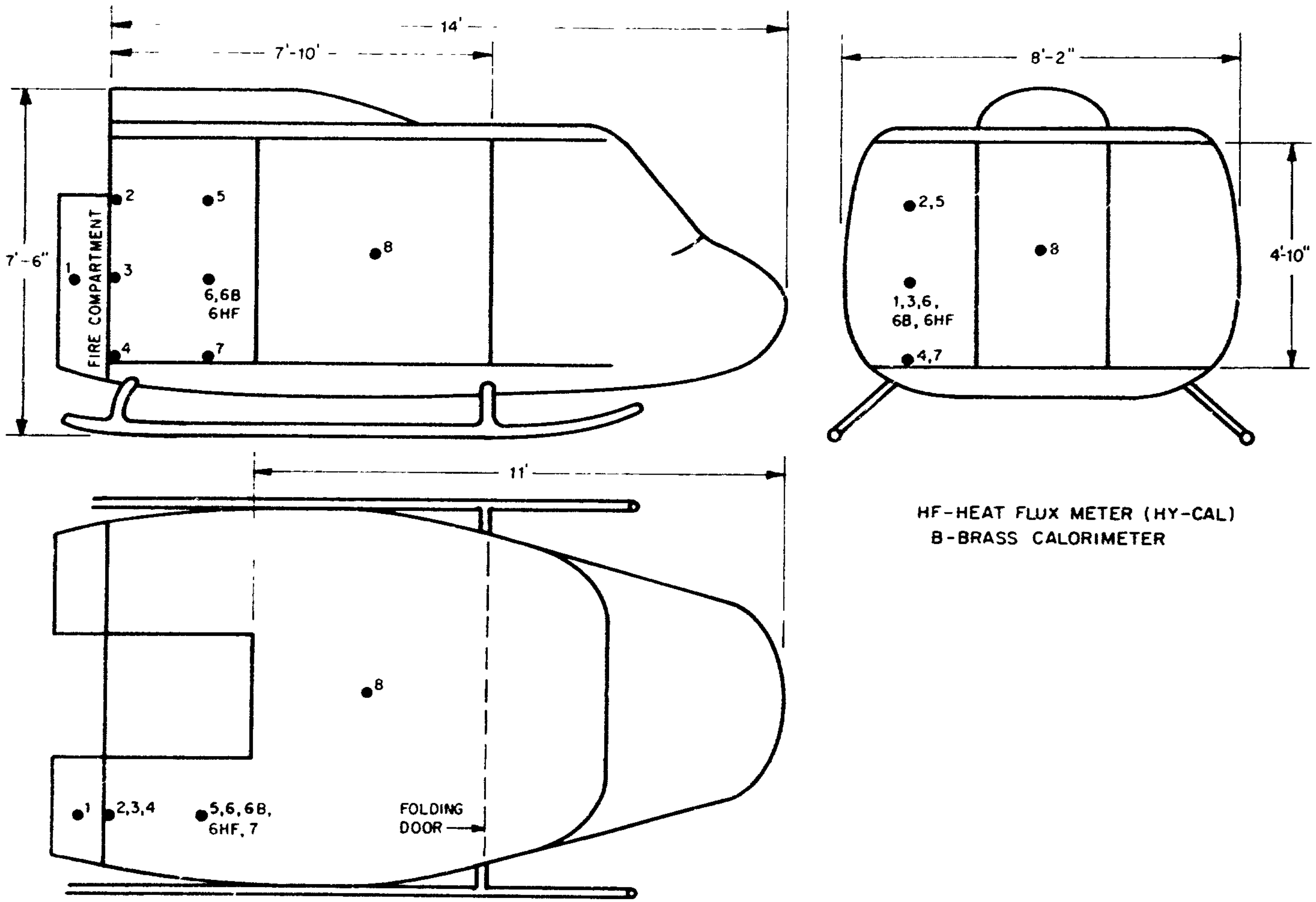
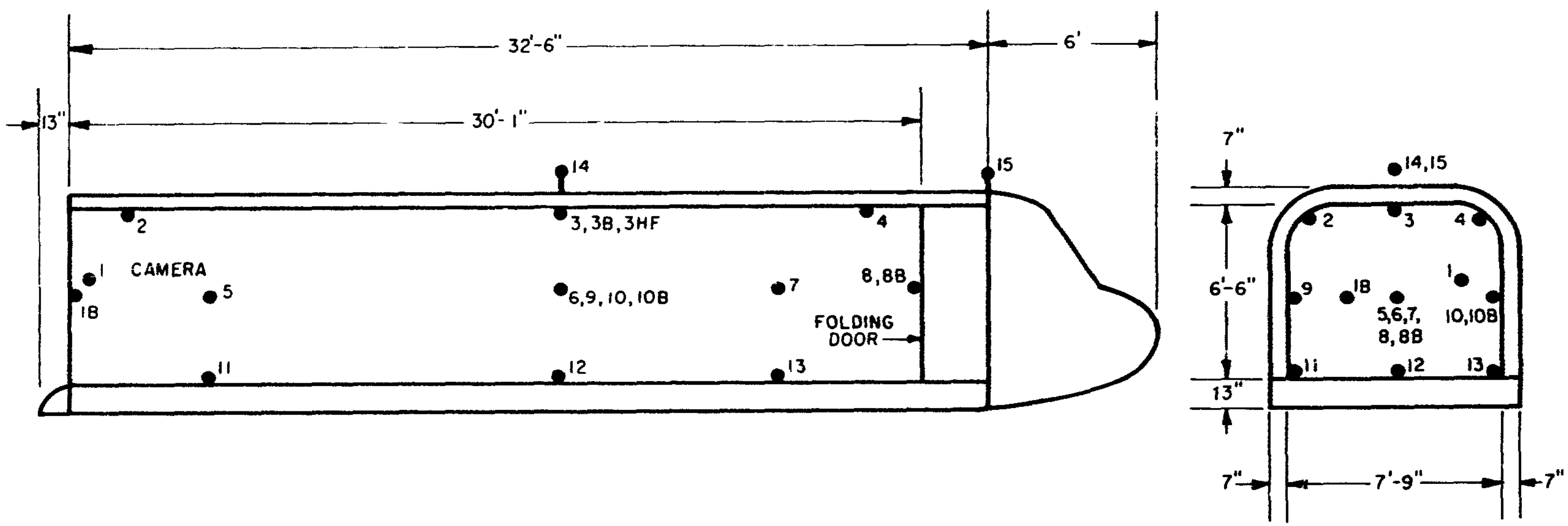


Figure 20. Thermocouple and Heat Flux Meter Distribution in the UH-1D for the In-Flight Tests.



HF - HEAT FLUX METER
B - BRASS CALORIMETER

Figure 21. Thermocouple and Heat Flux Meter Distribution in the CH-47.

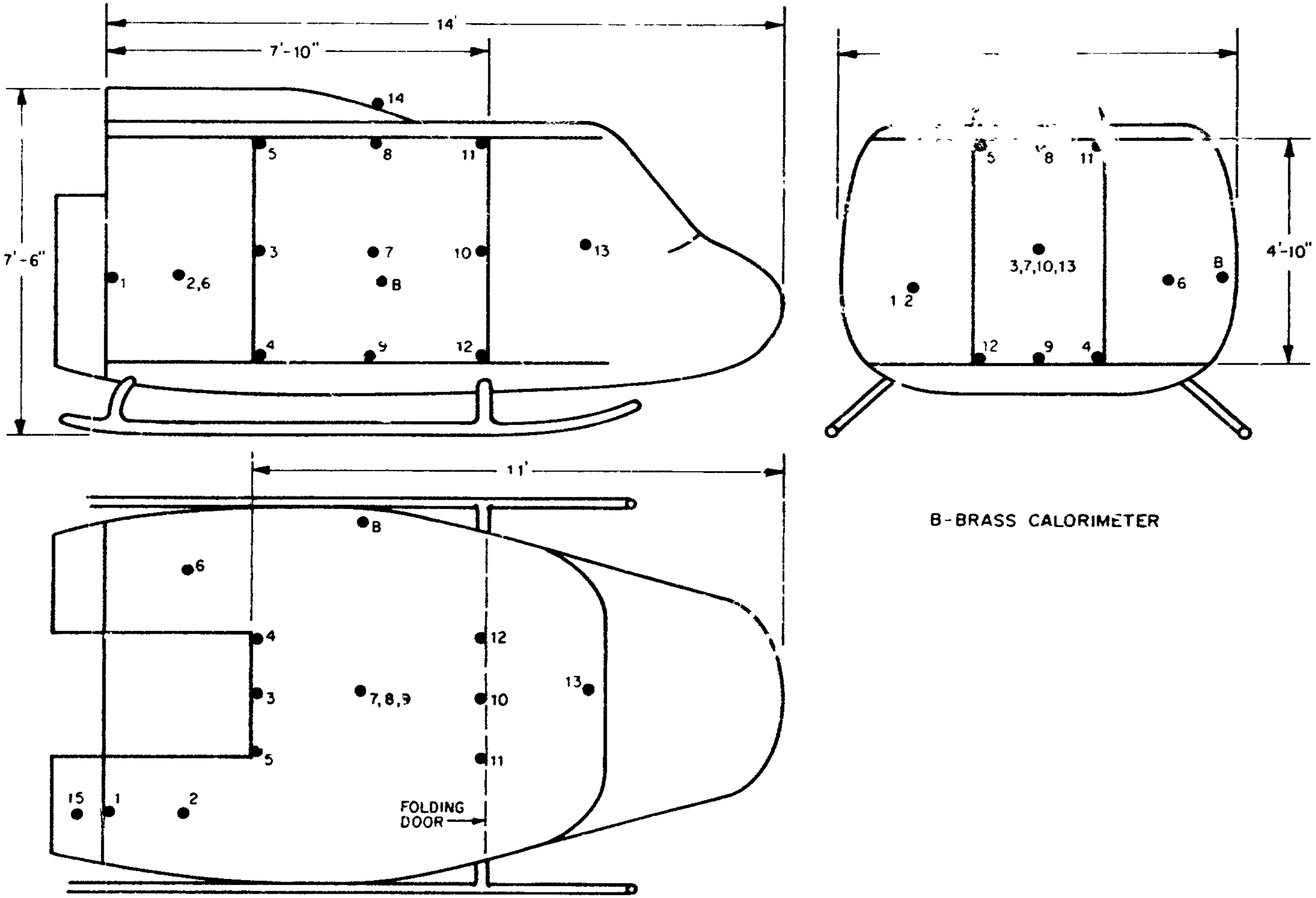


Figure 22. Thermocouple and Heat Flux Meter Distribution in the UH-1D for Postcrash Test.

DATA ACQUISITION

The output of the thermocouples, heat flux meters and smoke detectors was channeled to a terminal strip within the helicopter. Lead (extension) cables as well as gas sampling tubes and power lines for the vacuum pump and light sources were run through a 3-3/4-inch I.D. iron tube which extended some 50 feet from the helicopter interior to a protected instrumentation area. The tube was insulated to protect its contents from the fire.

The electrical extension cables were two conductor-shielded cables which minimized noise from extraneous electrical signals. Thermocouple and heat flux leads were connected to a VIDAR scanner which had been calibrated (NBS traceable).

The VIDAR recorded the data on magnetic tape which was read out later and the data printed out. It also recorded the time at the beginning of each scan. In addition to the VIDAR, the output of selected thermocouples was recorded on a strip chart recorder as a safeguard against the loss of the VIDAR data. Output from the smoke detectors was recorded on a separate strip chart recorder.

POWER SUPPLY

Power was needed to run three vacuum pumps, four 100-watt lamps in the interior of the CH-47, the light sources for the smoke detectors, the VIDAR scanner, a cooling water circulation pump for the heat flux meter, and the video system. A gasoline-driven power generator was used after it had been tested for constancy of voltage and frequency and shown to operate satisfactorily with all the recording equipment.

RESULTS

IN-FLIGHT FIRE SIMULATION TESTS

Figures 23 and 24 show temperatures of the various locations in the UH-1D helicopter throughout the two separate in-flight simulation tests. These locations have been identified in Figure 20. Figures 25 and 26 show the heat flux variation with time for each test as measured by the brass spheres and heat flux meter. As indicated earlier, both tests were conducted with the doors closed to allow better thermal measurements in the absence of wind. Smoke and toxic gases were not measured in these tests because it was assumed that in real-life the occupants would have opened the doors of the helicopter in case of an in-flight fire in preparation for egress after landing or to prevent smoke accumulation.

It should be noted that the heat flux data from the brass sphere is lower than the data from the total heat flux meter. This is because the meter was facing the hot wall of the fire compartment throughout the test, whereas the sphere could see the rest of the compartment which remained cold. Thus, the radiant component of heat flux was greater for the meter than for the sphere while the convective component was about the same.

Comparison of the data from the two tests shows that there are marked differences in the behavior of the two fires and in the corresponding temperatures and heat fluxes recorded inside the helicopter. It should be recalled that the in-flight fire compartment used in the first test had no cover, thus allowing more complete combustion of the fuel and higher temperatures to be recorded in both the fire and habitable compartments. The second compartment was partially covered, thus restricting the flow of air into the fire compartment. The flame was sootier than in the previous test. It was also noted that some unburnt fuel had accumulated in the bottom of the compartment at the conclusion of the second test. Although such a fuel-rich fire was expected to produce lower temperatures in the fire compartment, it is believed that the liquid JP-4 spray impinged on thermocouple 1 during this test, providing an unrealistic low temperature for the fire compartment.

The first in-flight test which utilized a coating of Albi mastic on the walls of the fire compartment resulted in the accumulation of large amounts of white smoke within the cabin. This is believed to have resulted from heating the ICU foam which had already been sprayed in the floor space in preparation for the large-scale tests and from the mastic itself. Also, there were direct penetrations

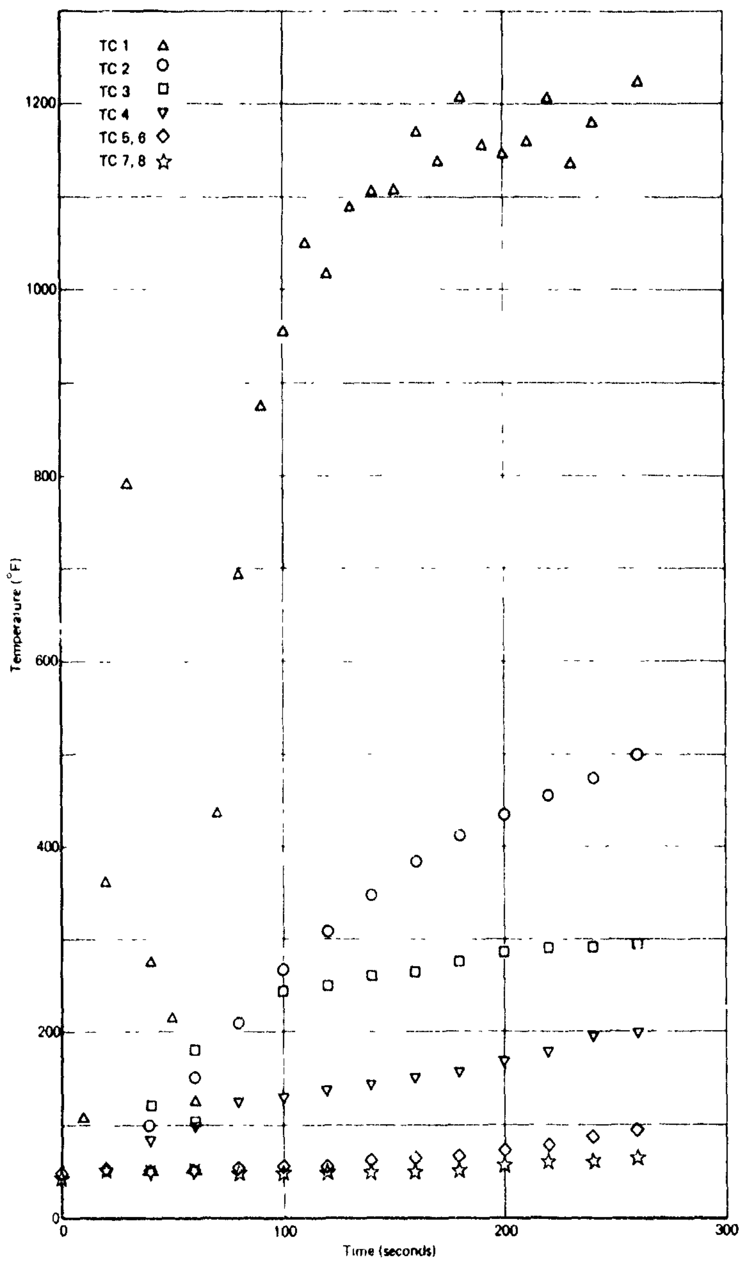


Figure 23. Temperatures Recorded During the UH-1D First In-Flight Fire Test.

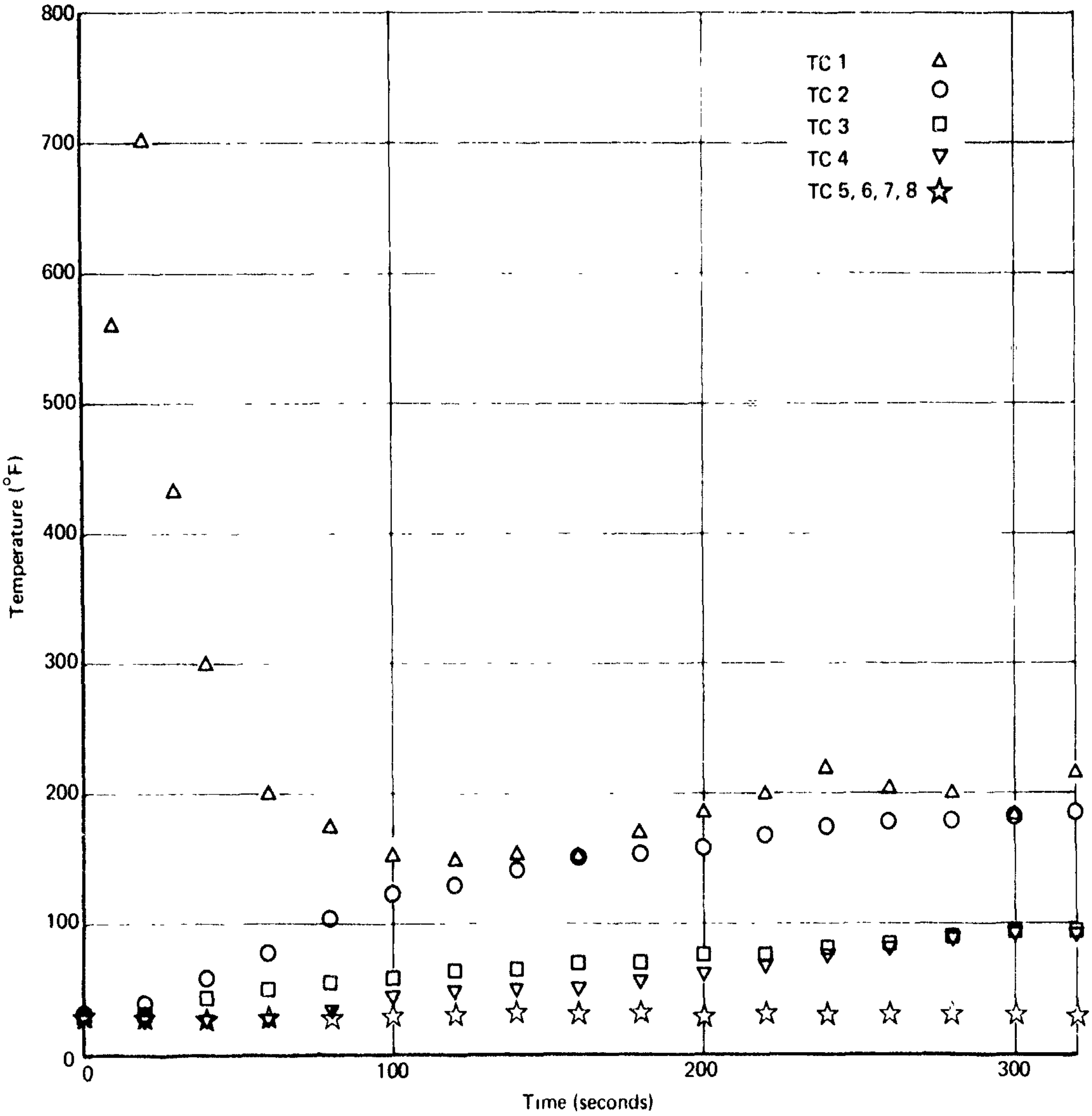


Figure 24. Temperatures Recorded During the UH-1D Second In-Flight Fire Test.

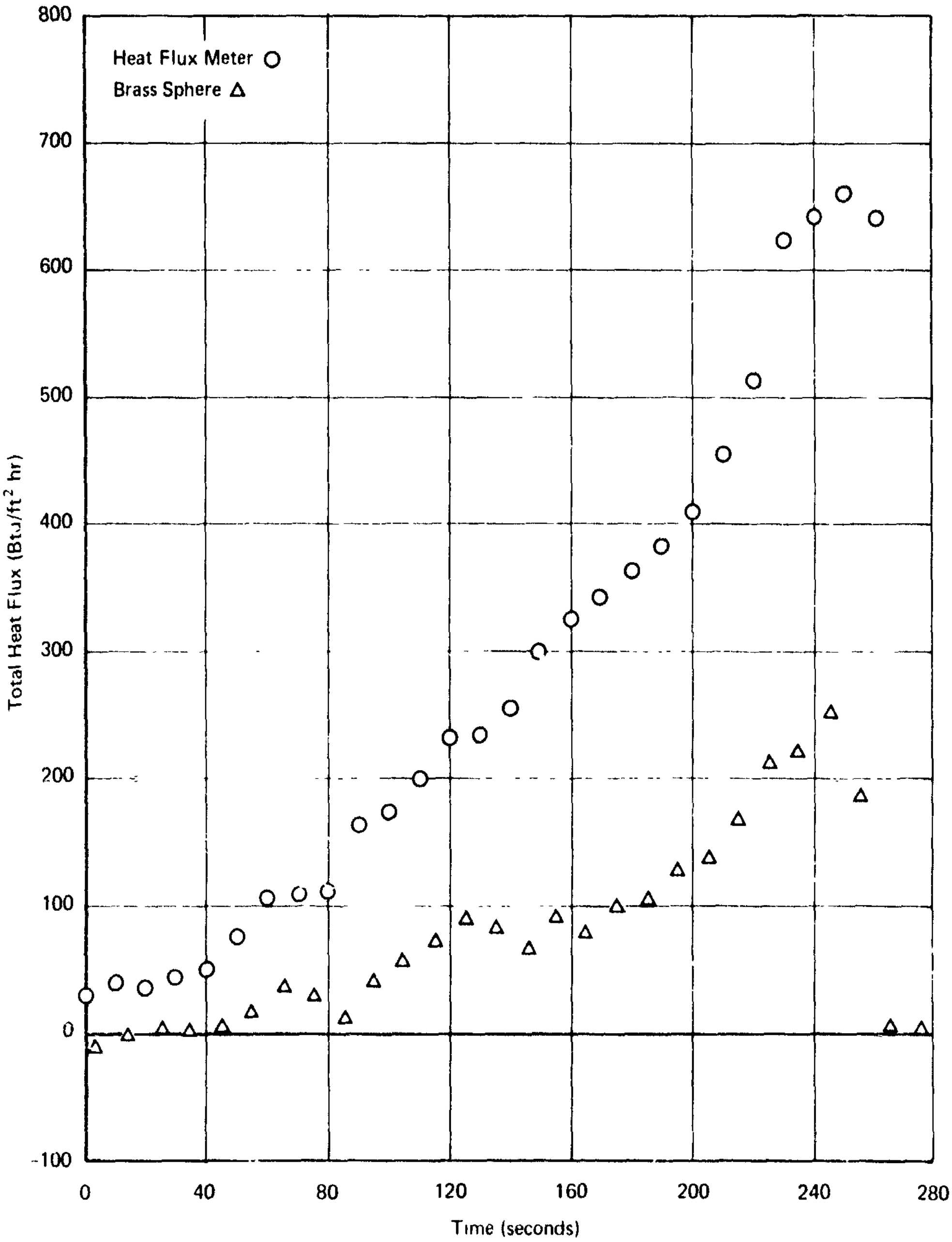


Figure 25. Heat Flux Data Within the UH-1D Cabin During the First In-Flight Fire Test.

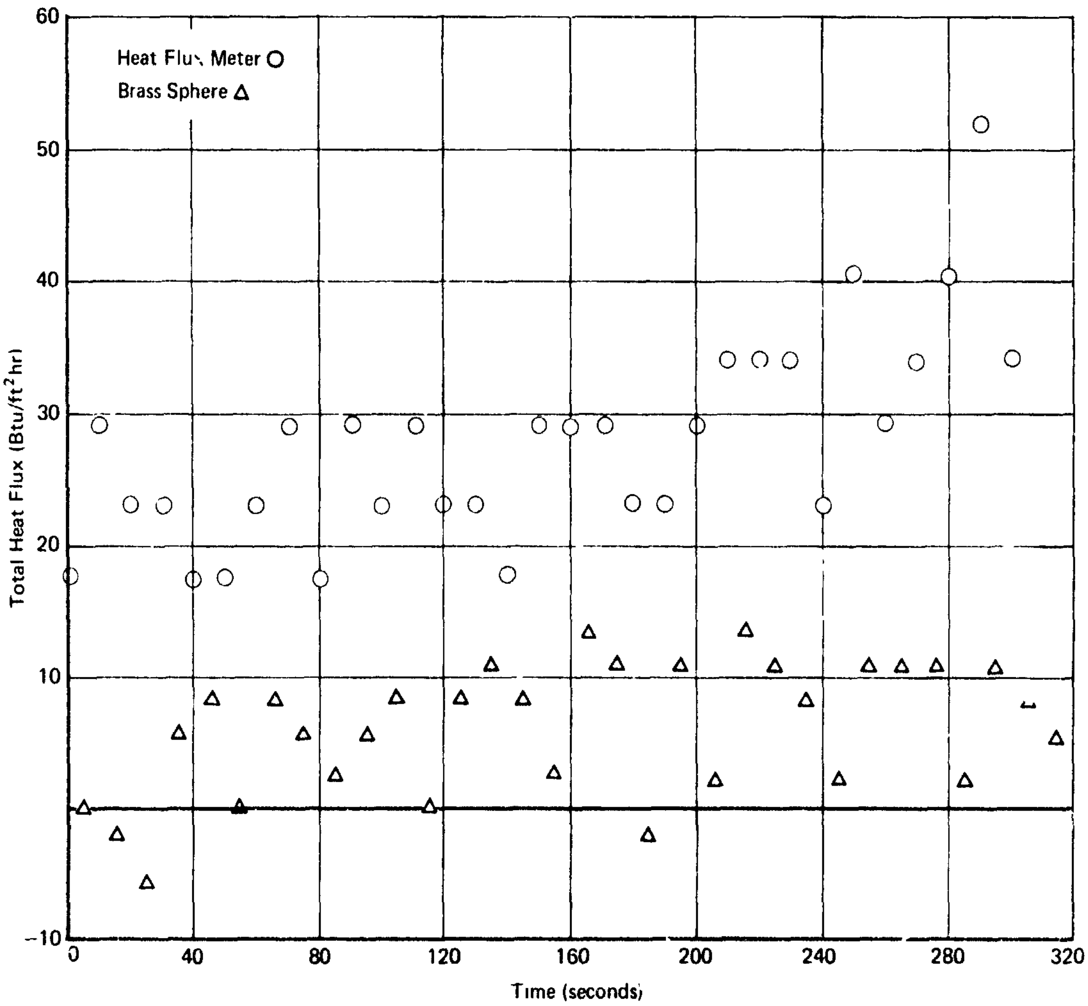


Figure 26. Heat Flux Recorded in the UH-1D During the Second In-Flight Simulation Test.

between the left compartment, the floor space and the habitable cabin. No such penetrations were present in the second case when BASF fire plate was used.

In both tests, air temperatures (and temperature rises) and heat fluxes recorded within the habitable cabin were far below human tolerable levels. One of the authors remained within the helicopter with the doors closed for the 5-minute duration of the second test without any discomfort.

It is concluded that in-flight fires can be protected against by lining the walls of potential fire compartments with intumescent mastic coatings (e.g., Albi Clad 89-X) or with an intumescent inorganic panel (e.g., BASF fire plate).

CH-47 POSTCRASH FIRE

Thermal Measurements

Temperatures taken at the various locations identified in Figure 21 and as recorded on the Vidar are plotted in Figures 27, 28 and 29. Heat flux measurements made with the brass spheres and the heat flux meter are shown in Figure 30. It should be noted that the heat fluxes recorded by the heat flux meter in this case were below those of the brass spheres at the same position. This is because the meter was pointing at a cooler spot on the wall while the sphere was receiving radiation from all hot walls.

It is noted from these plots that the duration of the data is only 160 seconds*, when the fire actually proceeded for more than 20 minutes. The reason for this is that power was lost due to a short in the line leading to a water circulating pump placed within the helicopter for cooling the heat flux meter.

By the time the shorted line was disconnected (after a lapse of about 5 minutes) the fire was of such intensity that the aluminum foil/glass wool mineral insulation on the iron pipe protecting the lead cables and thermocouples had melted and the PVC insulation on most thermocouple extension wires within the pipe had melted, thus shorting these leads.

The cause of the power failure could not be identified until the video tape recording of the interior was played back in slow motion. The tape showed that early in the fire an explosion had occurred

* Since the Vidar was set to record data every 10 seconds, the maximum duration of the data may have been 180 seconds (3 minutes).

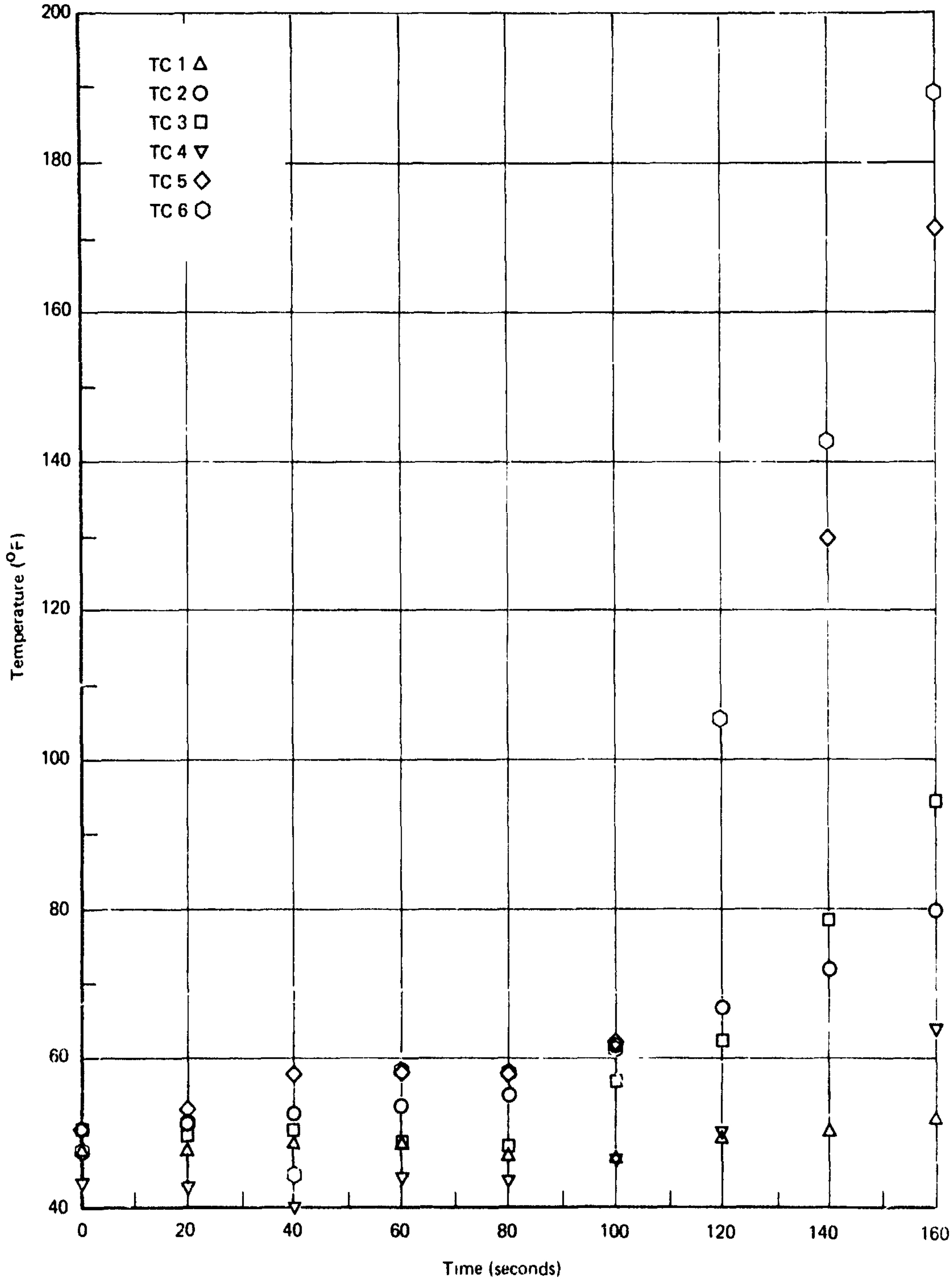


Figure 27. Temperatures Recorded in the CH-47 Cabin During the Postcrash Fire Test.

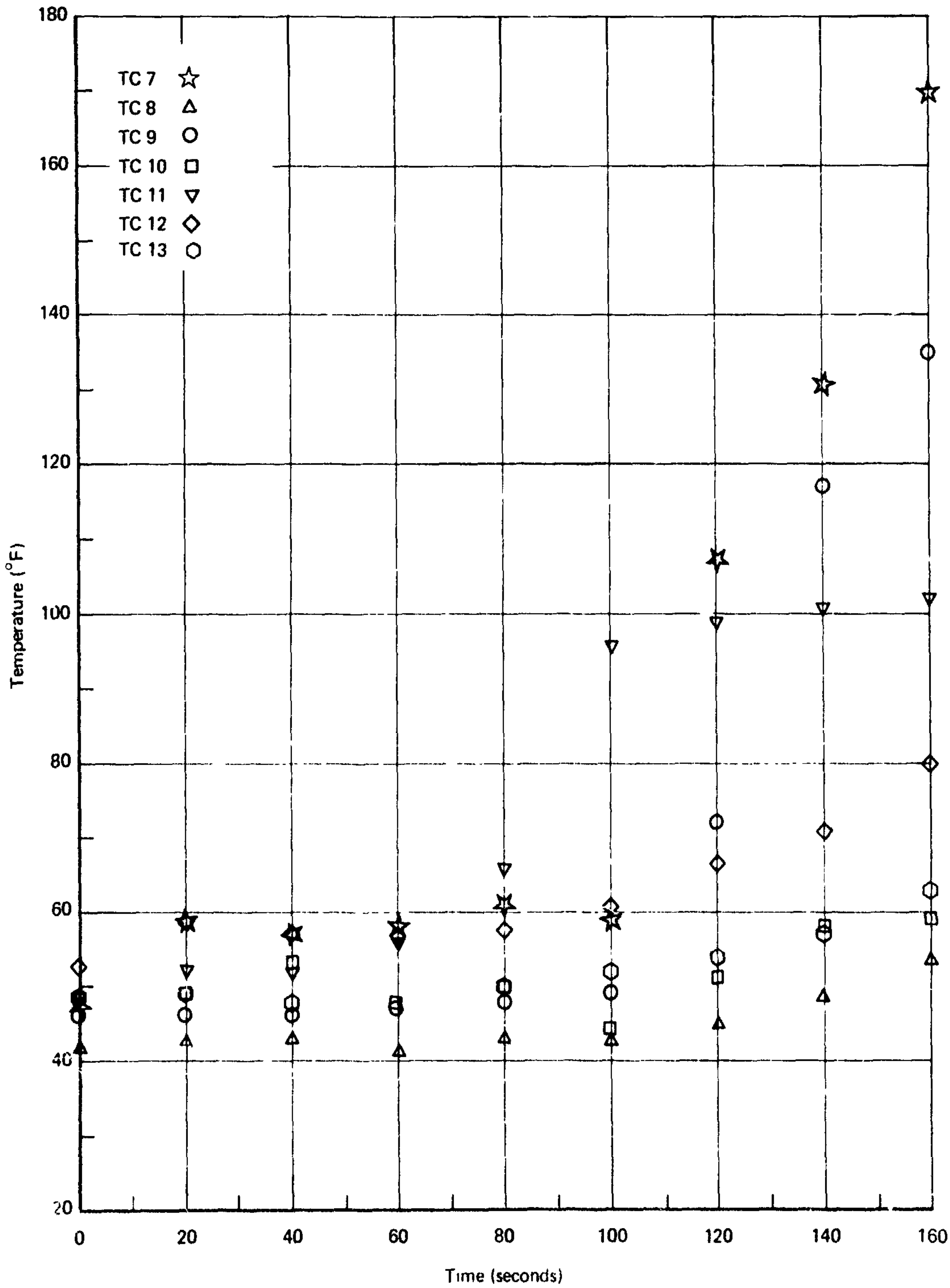


Figure 28. Temperatures Recorded in the CH-47 Cabin During the Postcrash Fire Test.

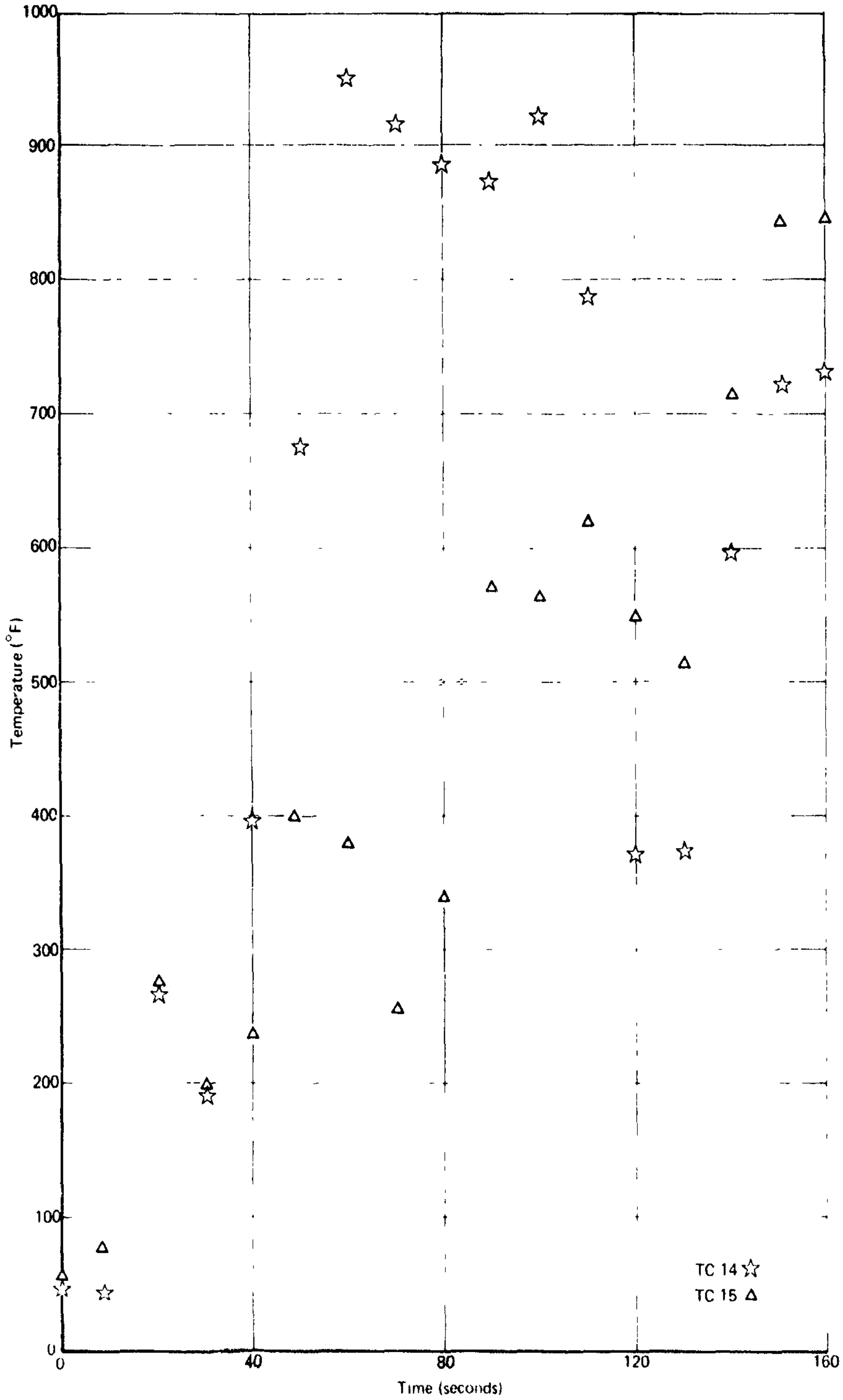


Figure 29. Temperatures Recorded by Thermocouples Exposed to the CH-47 Postcrash Fire.

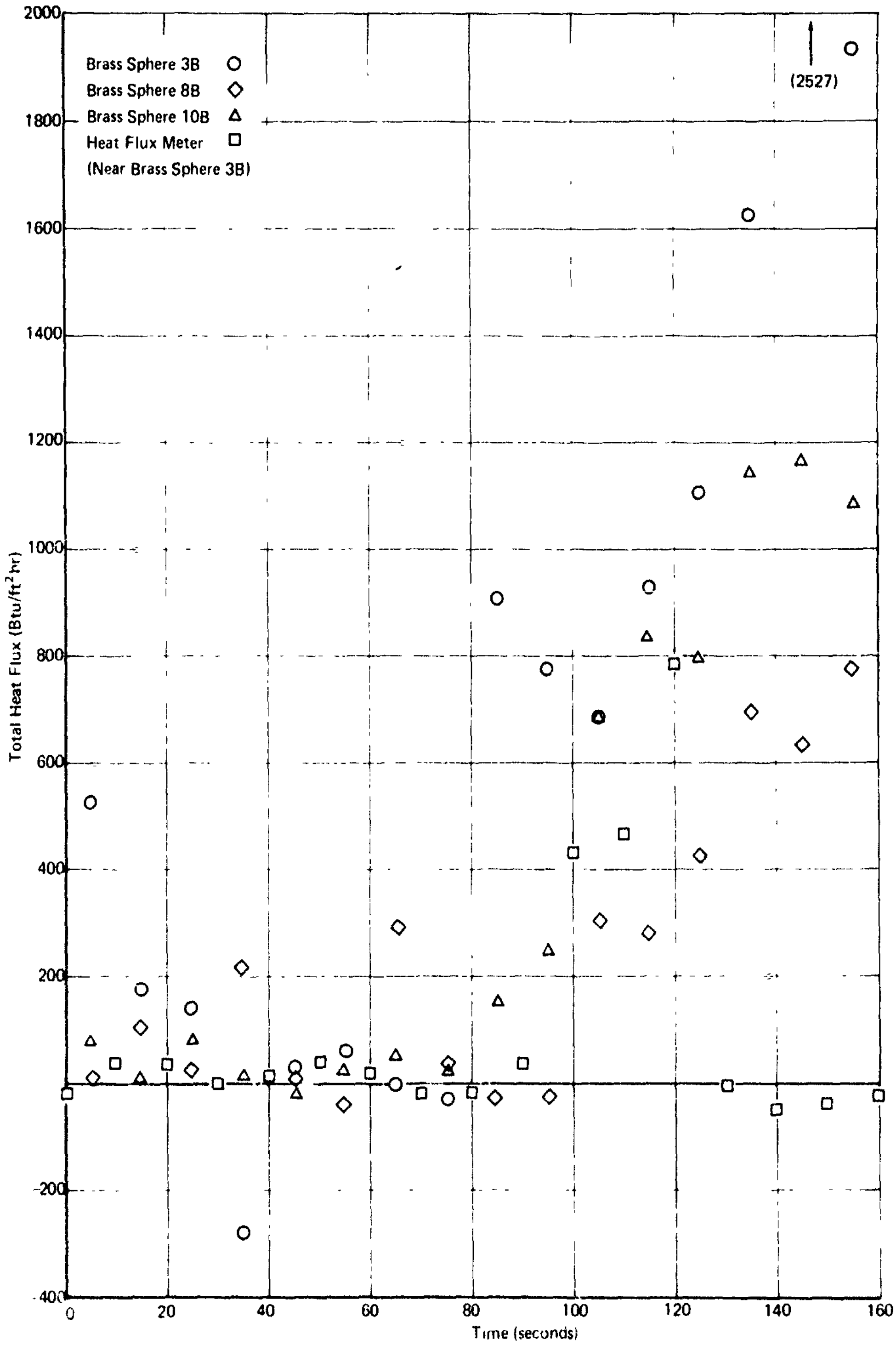


Figure 30. Total Heat Flux Recorded During the CH-47 Postcrash Fire Test.

within the helicopter. By back-timing the videotape from the moment power was lost, it was found that the explosion must have taken place within 15.7 seconds from ignition. An aluminum ribbed panel had been used to cover the floor space where the cargo door had been sealed and foamed to a height of about 4 inches, leaving an air space of about 7 inches. Apparently, fuel vapor had penetrated into this air space between the foam and the panel and eventually ignited. Figures 31 to 33 show the position of this space, the panel, and selected scenes from the video sequence. This floor space continued to burn after the explosion and was the only position within the helicopter that required extinguishment by the standby fire fighters. The electrical wiring leading to the pump motor was immediately above this space and is believed to have burned because of the fire there.

Examination of the temperature data during the first 160 seconds shows that the cabin air temperature (thermocouples 5, 6, 7) was not excessive (<200°F) and by itself would not have been fatal. The heat flux data as recorded by the brass sphere near the ceiling was above tolerable limit for humans (∿600-800 Btu/hr/sq ft). The maximum heat flux level recorded (2527 Btu/hr/sq ft) was far below the level (∿10,000 Btu/hr/sq ft) necessary to ignite cellulosic materials which may be present in a helicopter. Although the total heat flux level would have caused serious burns to the exposed skin surfaces of occupants, simple shielding of the hands and head would have prevented such burns. It is difficult to predict thermal conditions beyond the first 160 seconds because of the lack of data. It can be assumed, however, that temperatures and heat fluxes increased after that time and may have reached levels which were harmful to occupants.

Smoke and Toxic Gases

Figure 34 shows percent light transmission across a 20-foot path versus time. It can be seen that visibility dropped sharply after the first 20 seconds. Light transmission dropped to 50% within 50 seconds at the 4-foot level and 63 seconds at the 1-foot level. The video recording showed that the smoke developed immediately after the explosion.

Table VIII summarizes the concentrations of oxygen, CO_2, CO, and other reactive species generated in the CH-47. These results show that while oxygen concentration remained adequate, the concentration of the reactive species Fl—, Br—, CN—, and CO were above the threshold limit values (TLV) for 8-hour exposure as adopted by the American Conference of Governmental Industrial Hygienists (ACGIH). These concentrations are not necessarily lethal for the short duration involved. The major offender in this test was the high concentration (average of 350 mg/m^3) of particulates in the cabin air.

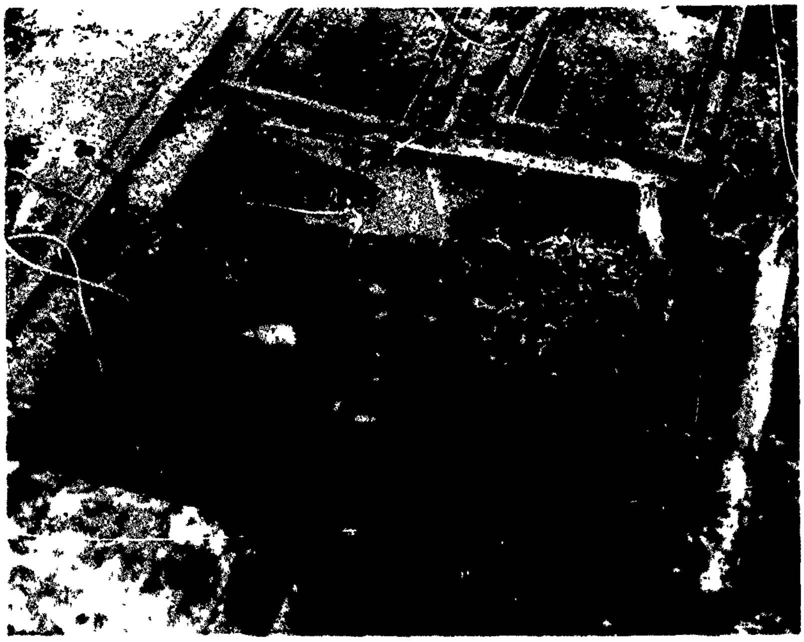


Figure 31. Cargo Door Where Explosion Occurred.

Figure 32. Cargo Floor Space With Aluminum Ribbed Panel Used as Cover (Damage to Walls From Firefighters' Water Streams).

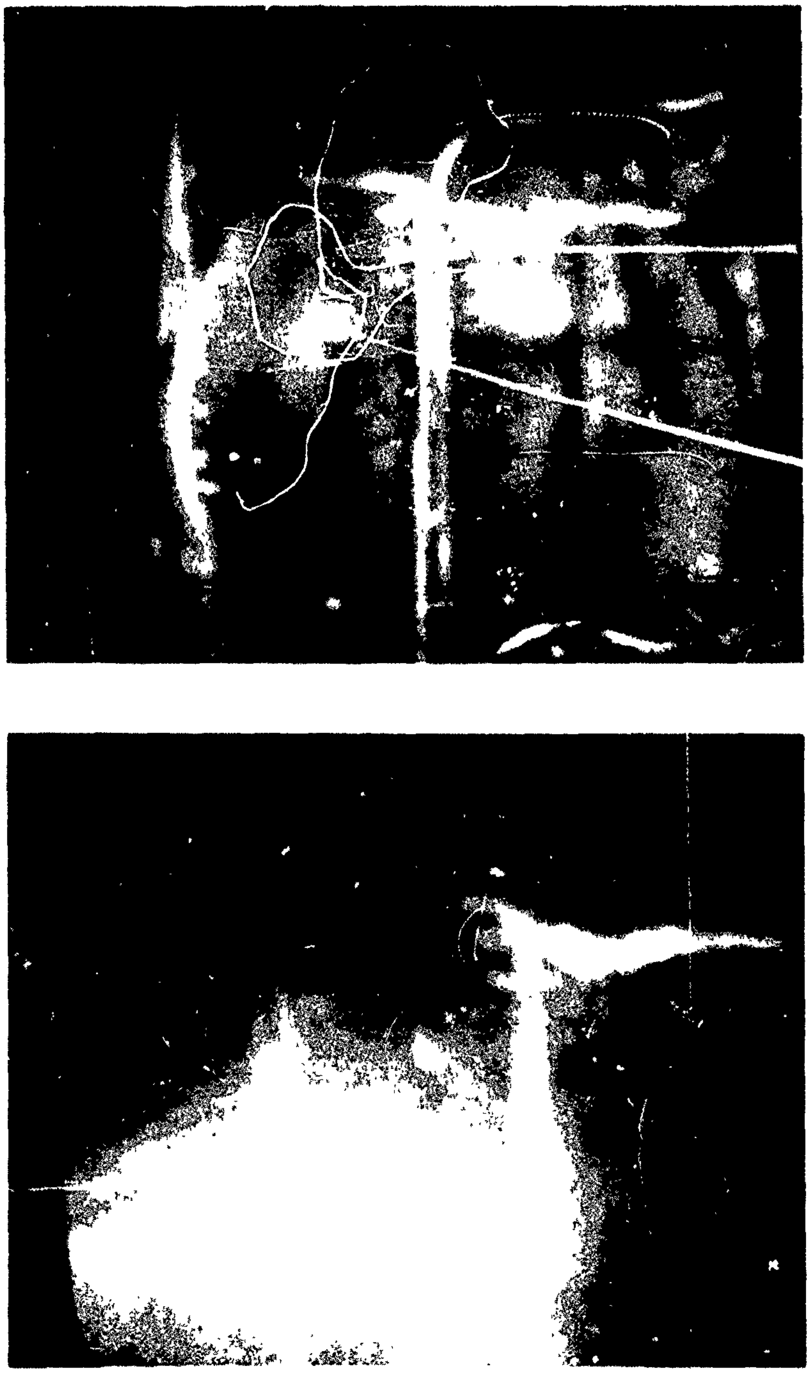
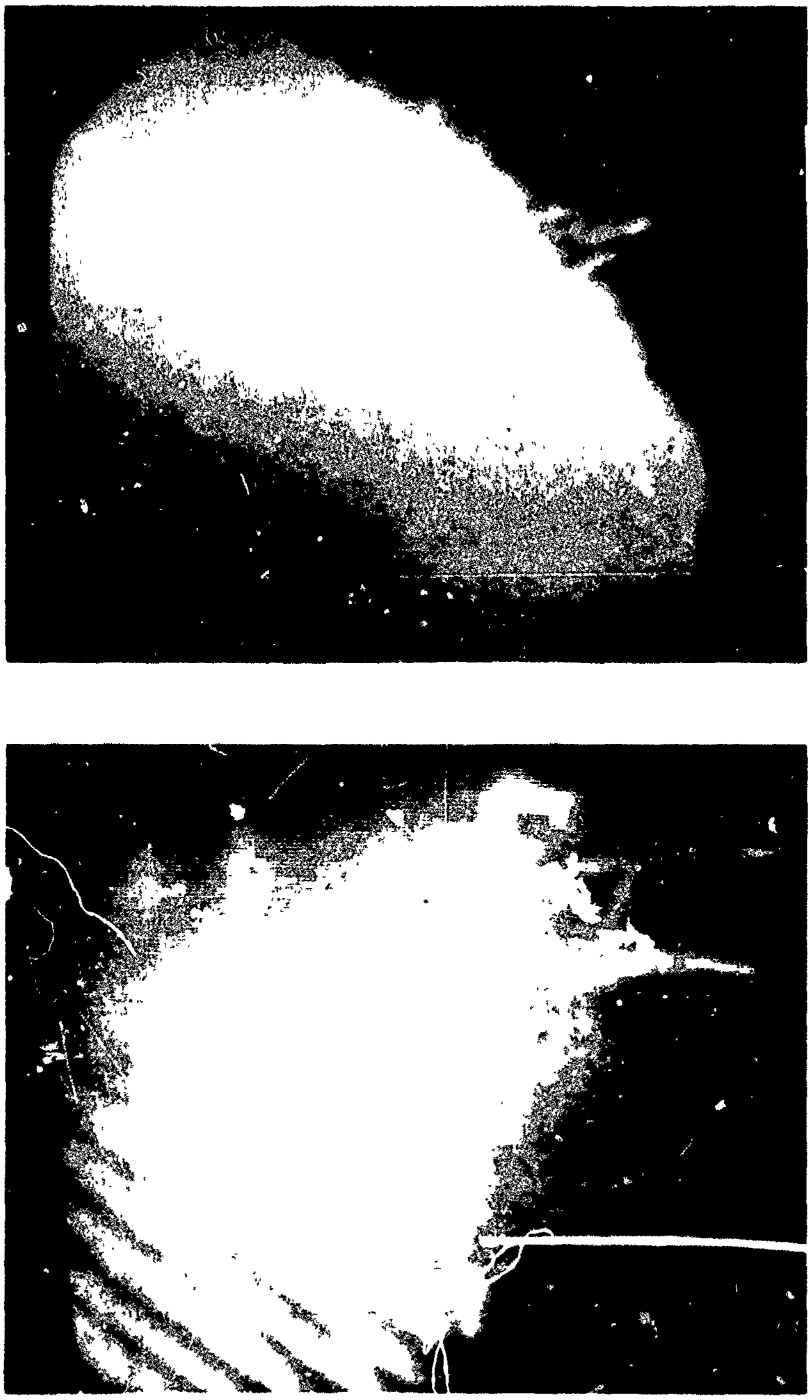


Figure 33. Sequence of Explosions in CH-47 Postcrash Fire.



c

d

panel

Figure 33. (Continued).

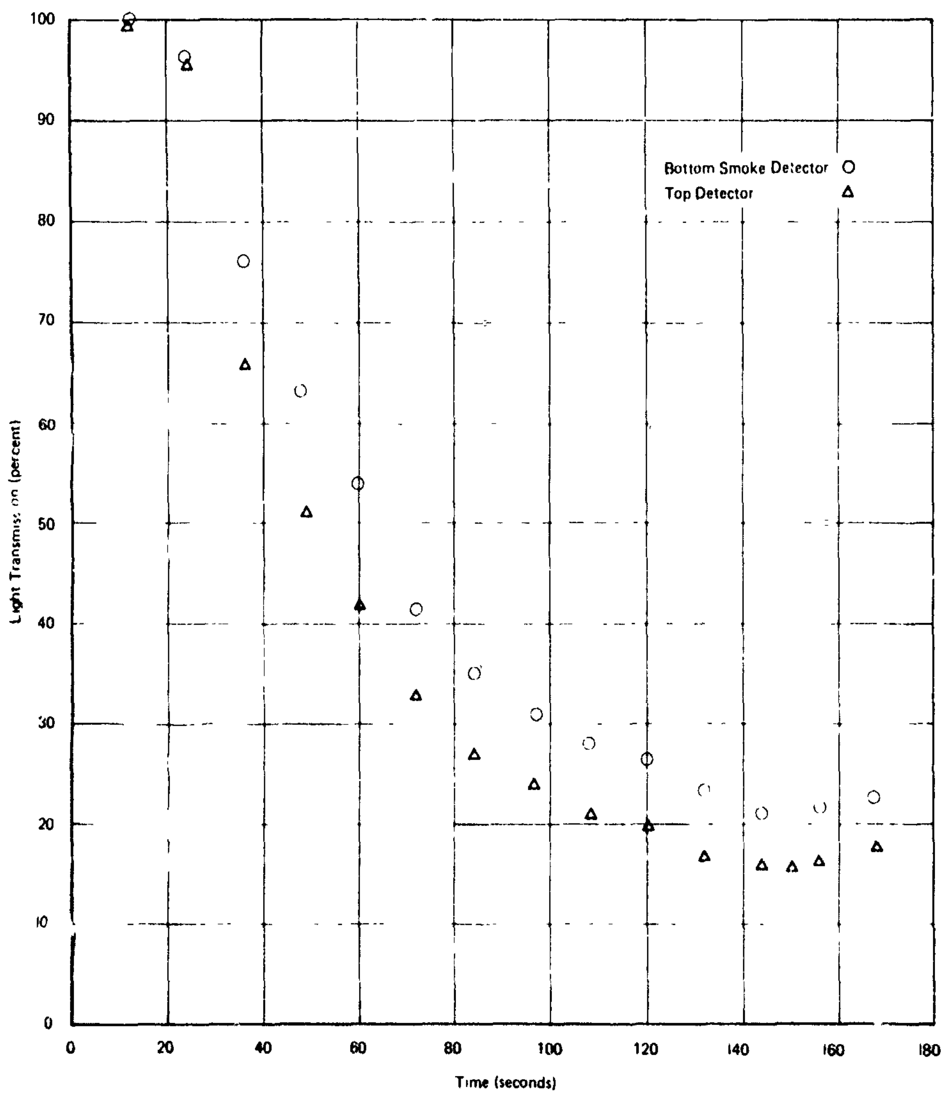


Figure 34. Light Transmission at the 4-Ft and 1-Ft Levels During the CH-47 Postcrash Fire Test.

Even though nothing is known about the synergistic effects of the species identified, especially when combined with the temperature levels recorded, it is felt that an occupant of the CH-47 helicopter could have survived this fire for the first three minutes possibly with 1st or 2nd degree facial and hand burns. The unavailability of data beyond that time does not allow further predictions.

CH-47 Integrity After Fire

The helicopter walls were inspected carefully after the test. Figures 35-41 show various scenes of the CH-47 interior and exterior. Figure 35 shows the condition of the interior fire plate paneling after the fire (the hole was made afterwards). Of particular interest are Figures 36 and 37 which are of the same location during application of the protective walls and after the fire. Dynaflex was used in the lower half, whereas the upper and adjacent sections were foamed with ICU foam. Both sections were paneled with BASF fire plate on the interior. During the fire, the Dynaflex fell to the outside as soon as the aluminum skin melted. The BASF panel remained in place until fire fighters used that opening to reach the floor space fire in the interior near the end of the test. The overall photographs of both sides of the helicopter (Figures 38 and 39) also show that it remained fairly intact except where Dynaflex was used or where the foam had no rib support. The cracks in the charred ICU foam (Figures 40 and 41) were not deep enough to reach the interior. There is no doubt that if ICU foam could have been used on all sections of the helicopter walls, the conditions within the helicopter would have been tenable for a longer period of time.

TABLE VIII. TOXIC GASES AND PARTICULATES GENERATED IN THE CH-47 FIRE

Reactive Species*		Concentration 4-ft level	1-ft level	TLV**
Fluoride	(Fl^-)	10 ppm	1.6 ppm	3 ppm
Chloride	(Cl^-)	5 ppm	<2.5 ppm	5 ppm
Bromide	(Br^-)	8 ppm	2.5 ppm	3 ppm
Cyanide	(CN^-)	13 ppm	3 ppm	10 ppm
Ammonia	(NH_3)	40 ppm	20 ppm	50 ppm
Particulates*		440;170 mg/m^3	600;200 mg/m^3	
Permanent Gases†				
Oxygen	(O_2)	20 %	17 %	-
Carbon Monoxide	(CO)	.05%	.05%	.005%
Carbon Dioxide	(CO_2)	0.3 %	0.2 %	.5 %

* Total time for sample was 10 minutes. Sample collected for 3 minutes after ignition until power was lost. After return of power, sample collection continued for another 7 minutes. Total volume of gas sampled = 30 liters.

† Sample taken 3 minutes after ignition.

** Threshold limit values for 8-hour exposure.

Figure 35. CH-47 Interior After Fire Looking Toward Cockpit Door (Hole in Wall Made by Firefighters).

Figure 36. CH-47 Interior Typical Wall Construction Before Fire.

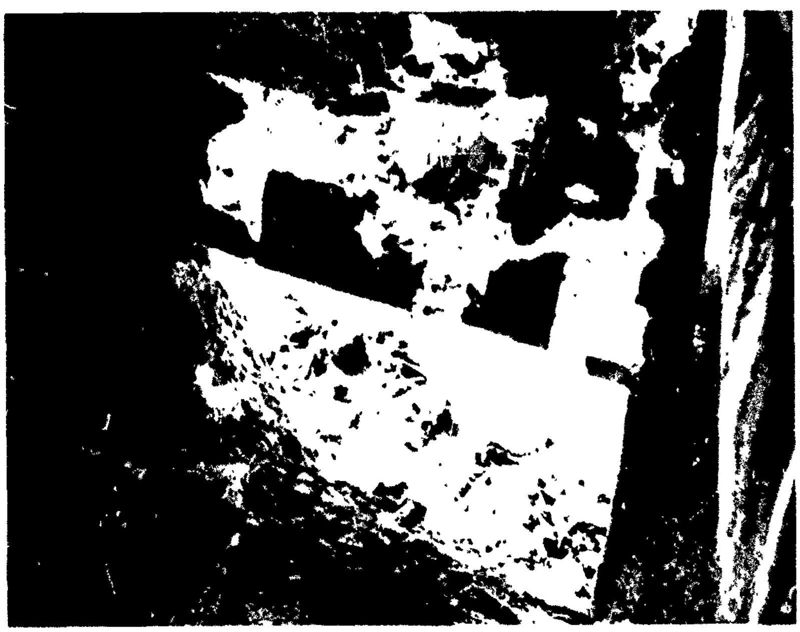


Figure 37. CH-47 Interior Typical Wall Construction After Fire.

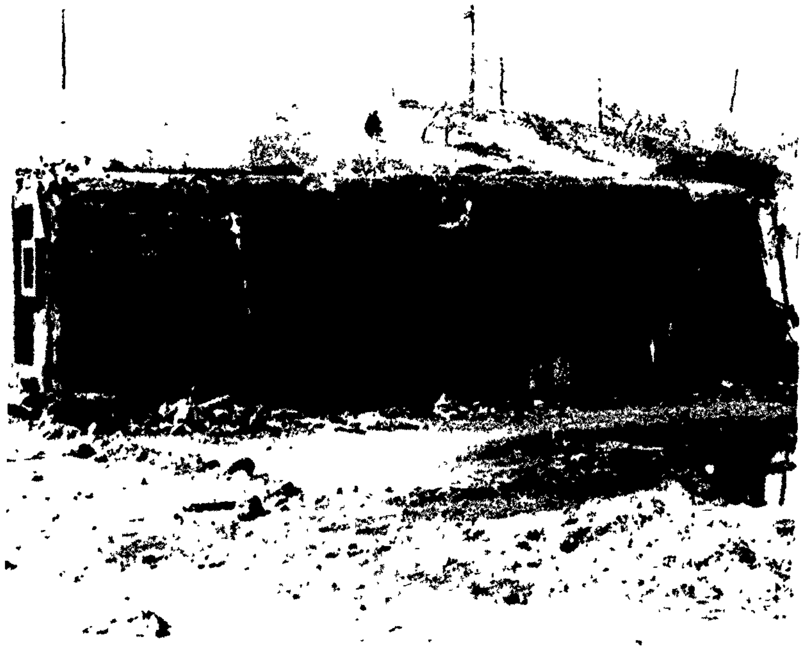


Figure 38. Right Side of CH-47 After Fire.

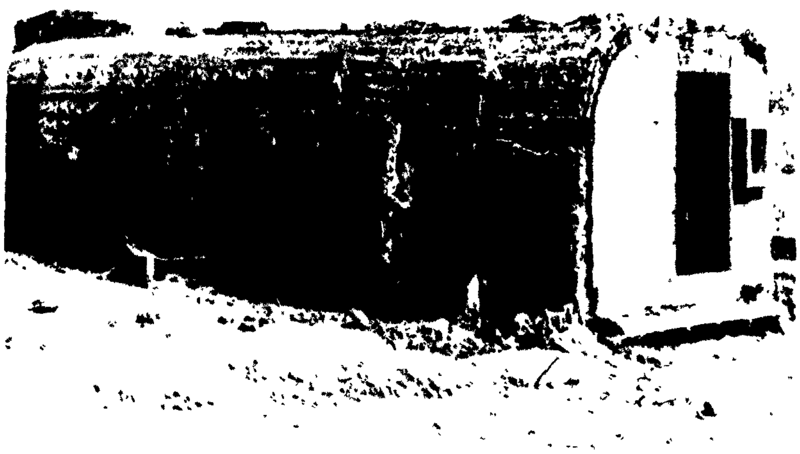


Figure 39. Left Side of CH-47 After Fire.

Figure 40. Unribbed Section Where ICU Foam Could Not Support Itself (Uncharred Foam Shows on Top Where Char Was Removed After Fire).

Figure 41. Typical Cellular Structure of Charred ICU Foam.

UH-1D POSTCRASH FIRE

Thermal Measurements

Because the UH-1D is smaller in size than the CH-47, fewer measurements were taken during the postcrash fire test. Locations of the various measurements are shown in Figure 22. Figures 42, 43, and 44 are plots of temperature versus time for the 8-minute duration of the test. Unlike the CH-47 test, all data were received and recorded since the umbilical iron pipe containing all leads and extensions was better protected. At the height of the fire, a cooling water stream was directed at the pipe for further protection.

The temperature data show that the maximum cabin air temperature (335°F) was that recorded by thermocouple 2 at 5 minutes after the beginning of the test. This thermocouple was close to the wall which received the maximum intensity of the fire because it was on the lee side of the wind where hot vortices were observed. Most other thermocouples recorded their maximum temperatures at about the same time with the exception of thermocouple 9. This thermocouple was placed on the floor above the ICU foam layer, and thus read very low temperatures throughout the fire with its maximum reading of 120°F occurring at 9 minutes 50 seconds. Thermocouple 7, which was placed in the center of the habitable compartment, gave a maximum cabin air temperature of 273°F.

The heat flux meter was not used in this test to avoid the need for a circulating pump for cooling water in the interior (and a recurrence of the power failure encountered in the CH-47 test) and because this test was expected to cause extensive damage to the helicopter and its contents. Only one brass sphere was used and its data (Figure 45) gave a maximum reading of 478 Btu/hr sq ft. The sphere was located near the upwind side of the helicopter (see Figure 22) where wall temperatures were not as high as those on the other side. It is expected that a sphere closer to the lee wall would have received a higher level of thermal radiation and convection and would have registered a higher total heat flux.

In summary, thermal measurements indicate that air temperatures and the heat flux within the UH-1D cabin during the first 3 minutes were lower than those encountered in the CH-47 fire during the same period. However, after 5 minutes the cabin air temperature was too high for human tolerance and may have caused respiratory injury to the occupants.

Smoke and Toxic Products

The variation in light transmission with time during the UH-1D test is shown in Figure 46. Table IX shows the concentrations of

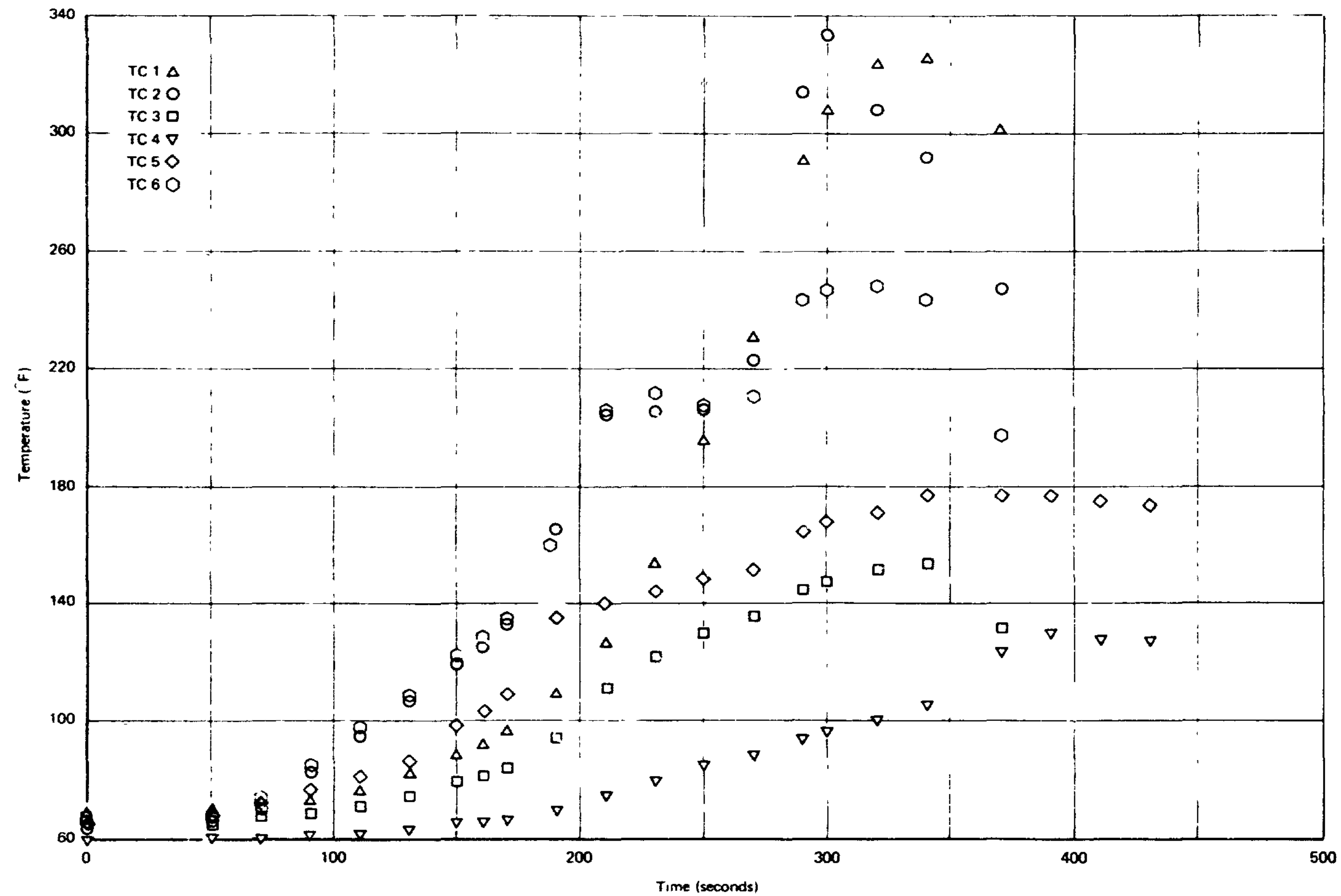


Figure 42. Temperatures Recorded in the UH-1D Cabin During the Postcrash Fire Test.

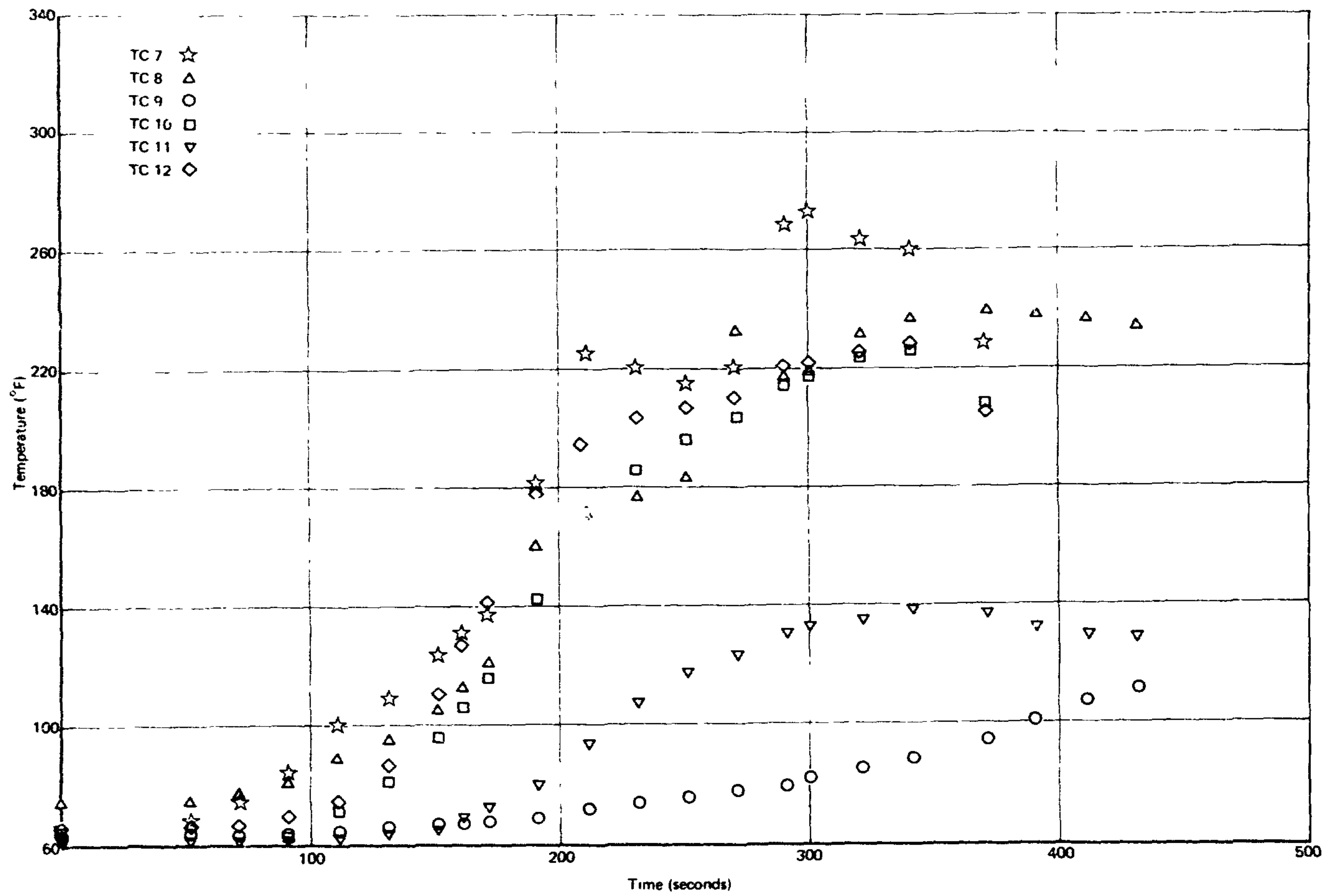


Figure 43. Temperatures Recorded Within the UH-1D Cabin During the Postcrash Fire Test.

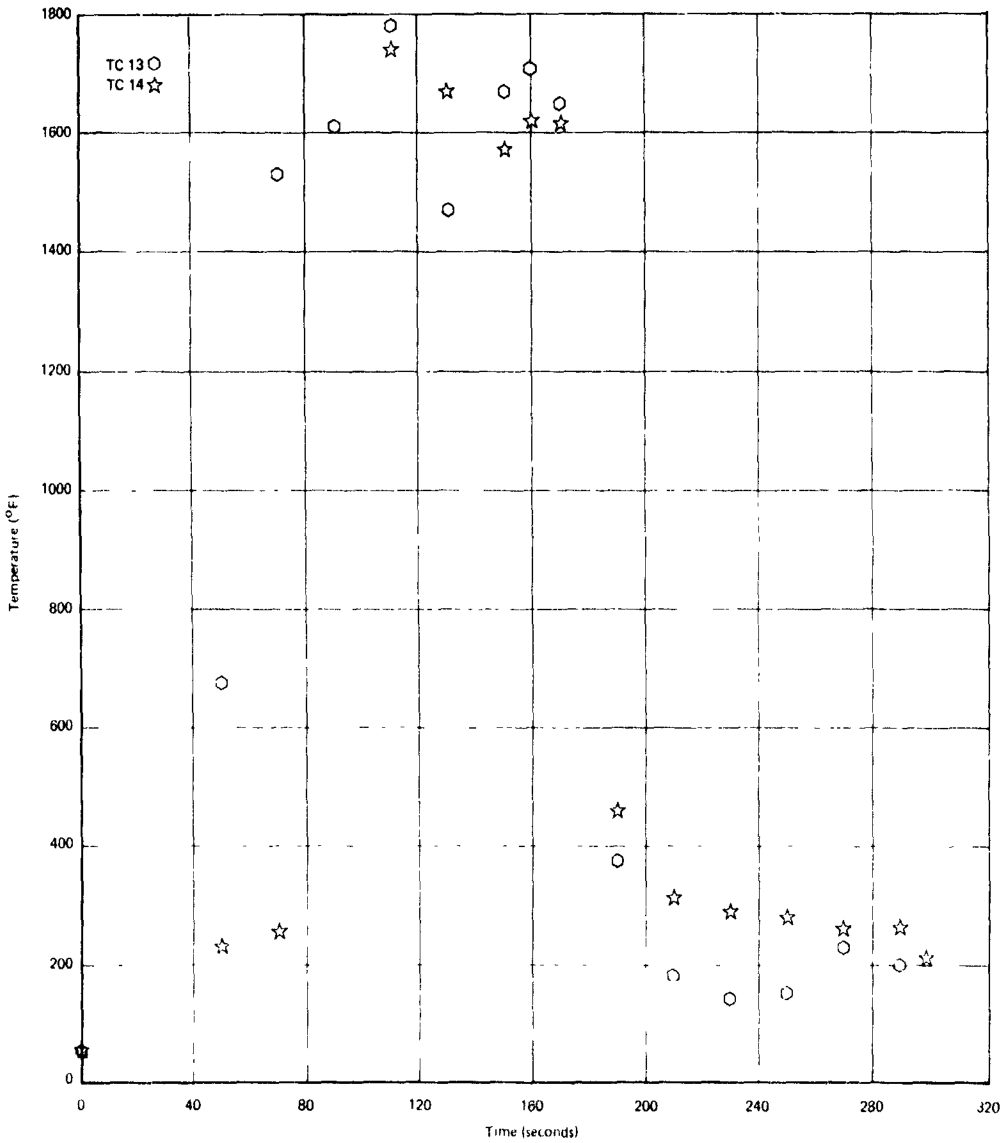


Figure 44. Temperatures Recorded by Thermocouples Outside the UH-1D Cabin.

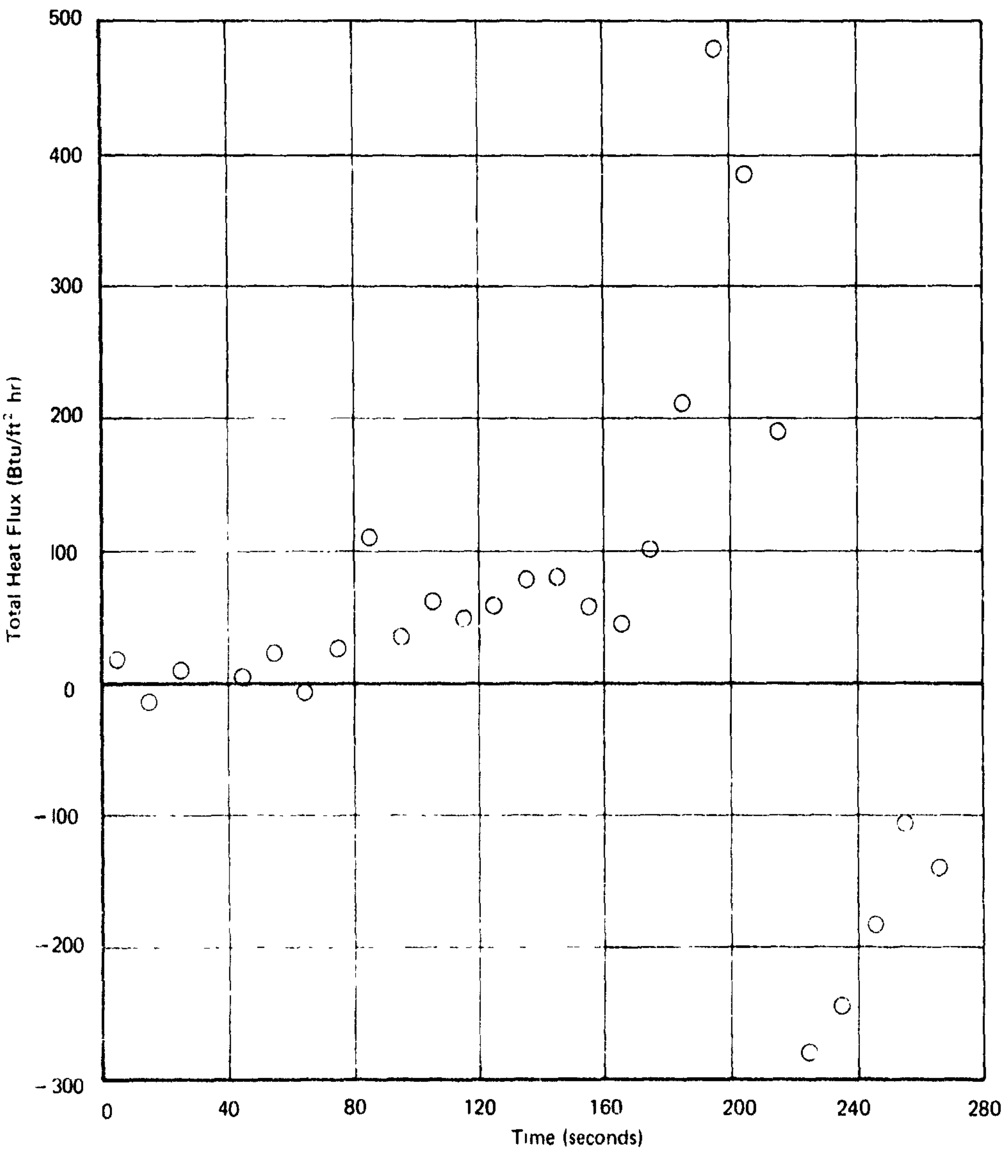


Figure 45. Total Heat Flux Measured by Brass Sphere Calorimeter in the UH-1D Postcrash Fire Test.

toxic gases and particulates generated in the UH-1D cabin during this fire. It can be seen that large amounts of smoke and particulates were generated very early in this test also. The average particulate concentration over a 7-minute period was 1600 mg/m^3 (see Table IX). Figure 46 shows that 50% light transmission occurred at 30 seconds from ignition. The high levels of smoke can be attributed to the absence of a tight seal between the doors and the floor and the interior walls. Furthermore, unlike the CH-47, the UH-1D bottom was raised above the ground by about 1 foot, which is the height of the landing skids. This allowed JP-4 to burn underneath the helicopter (until the skids collapsed), thus pyrolyzing the ICU foam in the floor. Because of the high temperatures to which the BASF fire plate was exposed in this test, larger quantities of steam were generated within the cabin than in the CH-47 where fire plate was not exposed directly to the fire. The steam generated in the UH-1D may have contributed significantly to the reduction in light transmission.

Because a smaller quantity of ICU foam was used in the UH-1D than in the CH-47, smaller concentrations of the reactive species were observed. However, because the UH-1D was not as air tight as the CH-47, higher concentrations of carbon monoxide and carbon dioxide were recorded, especially during the first three minutes. Nevertheless, the concentrations of the reactive species, CO, and CO_2 were not considered to be high enough by themselves to pose a threat of injury or fatality to occupants for the short duration of the fire. However, combined with the high cabin air temperatures and the presence of irritant particulates, permanent respiratory system damage is very likely to have resulted.

UH-1D Integrity After Fire

Figures 47 and 48 show the general condition of the UH-1D after the fire. The skids collapsed after about three minutes from ignition. Figure 47 shows the upwind side of the helicopter. The aluminum sheets covering the windows were protected with Albi mastic, while the section just below that was painted with Firehold intumescent paint. Because of the wind direction, it is difficult to assess the contribution of these wall treatments toward the survival of the aluminum walls on this side, when the aluminum on the lee (hotter) side was completely melted (compare Figure 47 and 48). The BASF fire plate on the lee side sagged because of the absence of any formers or ribs. However, penetrations were small and apparently did not contribute much towards increasing overall air temperatures or toxic product concentrations in the cabin.

Of the two compartments that were used to conduct the in-flight fire simulation tests, only the one that was paneled with fire plate survived. The unprotected front and aft sections of the helicopter were completely destroyed in the fire.

TABLE IX. TOXIC GASES AND PARTICULATES GENERATED IN THE UH-1D FIRE

Reactive Species*		Concentration† Probe #1	Concentration† Probe #2	TLV**
Fluoride	(Fl^-)	0.9 ppm	1.6 ppm	3 ppm
Chloride	(CL^-)	<2.4 ppm	<2.4 ppm	5 ppm
Bromide	(Br^-)	2.3 ppm	3.7 ppm	3 ppm
Cyanide	(CN^-)	8 ppm	10 ppm	10 ppm
Ammonia	(NH_3)	40 ppm	20 ppm	50 ppm
Particulates*		2000, 1700, 800, mg/m^3		

Permanent Gases

Time	Sample Point	Oxygen (O_2)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)
3 minutes after ignition	Probe #1	21%	0.13%	1.6%
	Probe #2	20%	0.16%	1.6%
6 minutes	Probe #1	20%	<0.03%	1.1%
	Probe #2	20%	<0.03%	1.8%
9 minutes	Probe #1	21%	<0.03%	0.3%
	Probe #2	21%	<0.03%	0.2%
TLV**		--	.005%	.5%

*Total time for sample was 7 minutes. Total volume of gas sampled = 21 liters.

** Threshold Limit Values for 8-hour exposure.

† Sampling probes were close together and near the middle of the helicopter.

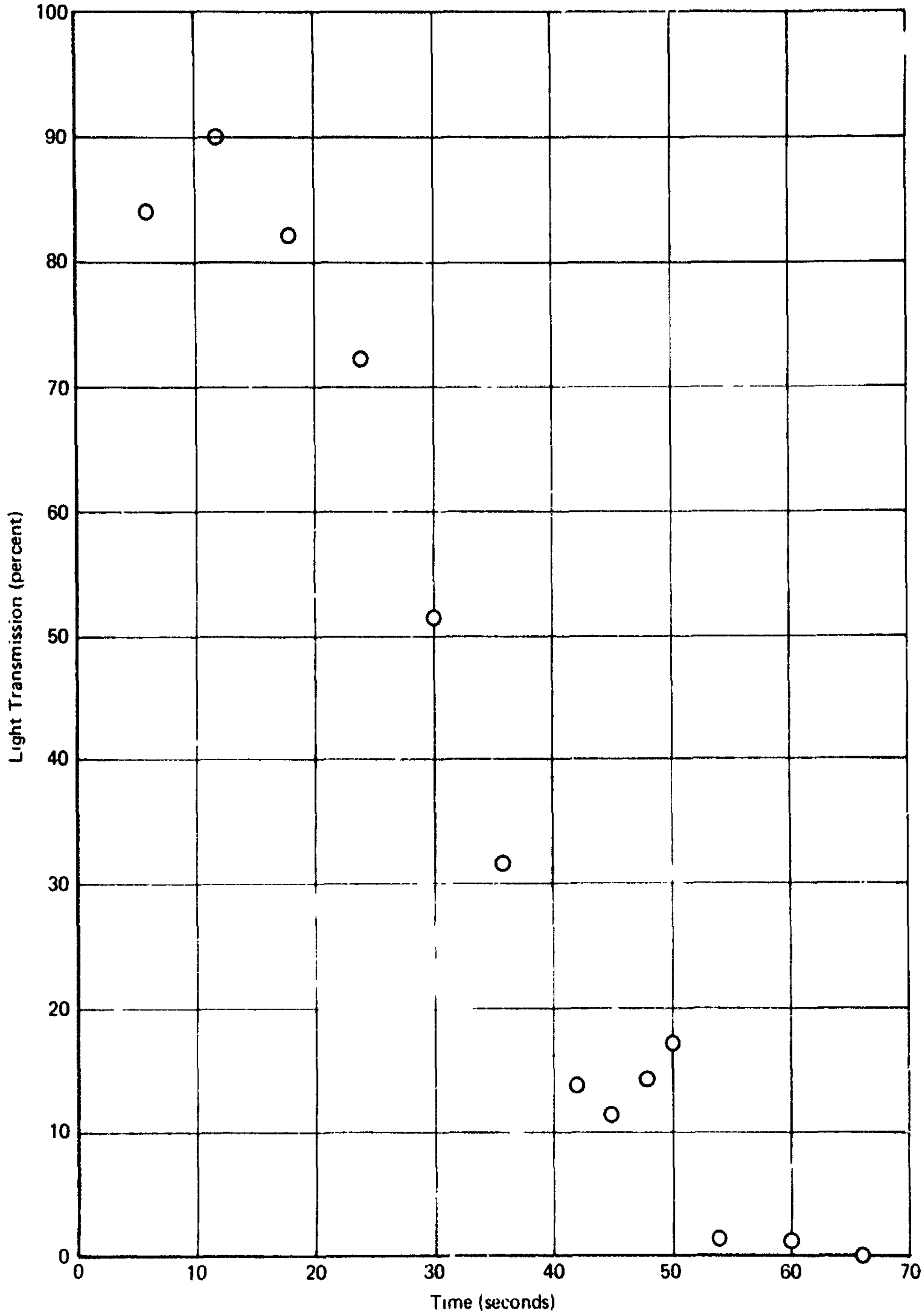


Figure 46. Light Transmission in the UH-1D Cabin During the Postcrash Fire Test.

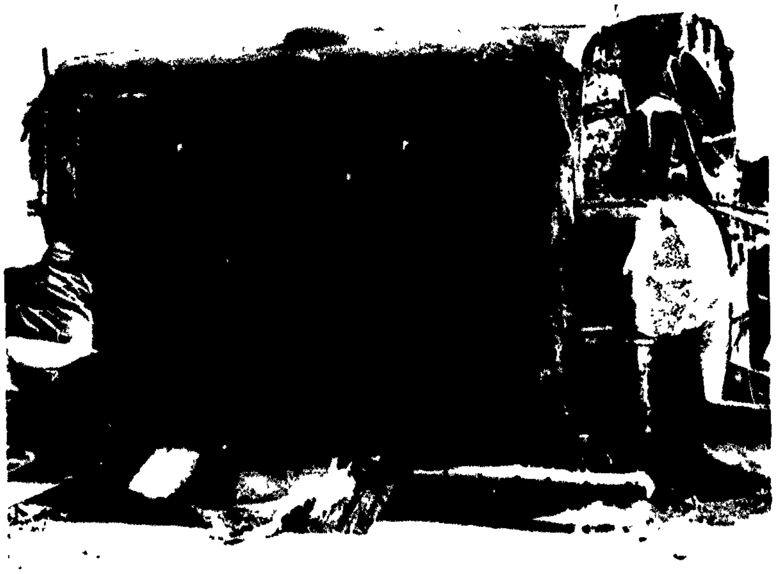


Figure 47. Upwind Side of UH-1D After Postcrash Fire Test.

Figure 48. .ee Side of UH-1D After Test Showing Absence of Aluminum Walls and Sagging Fire Plate Walls.

CONCLUSIONS AND RECOMMENDATIONS

The results of the in-flight and postcrash fire tests conducted on the UH-1D and CH-47 lead us to the following conclusions:

1. Fires occurring during flight in compartments other than the habitable compartment can be protected against by lining potential fire compartments with an intumescent mastic coating or a sodium silicate hydrate panel.

2. Presently used Plexiglas windows are the weakest points in a helicopter during a postcrash fire.

3. If windows can be protected appropriately, the survivability of occupants in postcrash fires can be increased significantly by insulating the interior walls with isocyanurate foams and sodium silicate hydrate panels. However, the unreliability in performance of the protective wall materials (especially in areas where wiring and tubing have to be left accessible or where the walls have been damaged by the crash), the unknown effects on humans of smoke and particulates, and the weight and cost penalties render such an approach subject to serious questions.

Our recommendations are as follows:

1. The protection against in-flight fire should be pursued further by the U. S. Army. Recommended materials should be further tested against fires in various types of compartments and the weatherability of the materials evaluated.

2. Protection of the interior walls of the habitable compartment against postcrash fires should not be pursued any further.

3. Approaches toward enhancing the survivability of occupants should involve the development of personal protective clothing and masks, the improvement of the crashworthiness of the fuel tanks, and the utilization of active fire suppression devices on board.

TABLE X. FURNACE TESTS - UNCOATED (SHINY) ALUMINUM

Panel No.	Time To Burnthrough (min:sec)	Maximum Box Air Temperature (°C)	Maximum Panel Temperature (°C)	Heat Flux (Btu/ft^2 sec)
A-1	1:00	98	122*	9.7
A-2	2:30	137	192*	10.8
A-3	2:54	117	314	10.2
A-4	2:30	122	-	10.7
A-5	1:48	137	152*	12+
A-6	2:30	112	433	10.7
A-7	1:48	110	386	11.0

*Thermocouple became disconnected.

TABLE XI. RESULTS OF FURNACE TEST ON PAINTS AND COATINGS

Panel No.	Panel Description	Wt. Mtl. on Panel (gm)	Time to Burnthrough (min:sec)	Max. Encl. Air Temp. (°C)	Max. Panel Temp. (°C)	Coat Flux (Btu/sq ft sec)	Observations
2	Val. Chem wash primer Albi Clad 89X; 11 mils	194	4:22	-	-	10.1	Mastic on inside. Heavy smoke inside.
3	As above	166	1:36	98	443	10.1	Mastic on outside. Smoke inbox, char erodes.
5	Val. Chem primer, Firehold; 10 olive green, Acrylic clear mist	31	1:30	-	-	-	Little smoke. Char erodes.
13	Val. Chem primer Albi 107X Albi 144; 40 mils	55.6	1:15	93	132*	9.7	Char erodes.
14	Val. Chem primer Albi 107X Albi 144; 42 mils	79.0	1:21	103	367	9.2	Char erodes.
17	Val. Chem primer Albi 107X Albi 144; 40 mils	64.0	2:10	108	358	9.7	Char erodes.
18	Val. Chem primer Albi 107X Albi 144; 40 mils	61.9	1.7	98	127*	9.4	Char erodes.
56	Pfizer "Firex" .215 in.	1010	15:20	142	256	9.6	Irritating noxious fumes.
54	Pfizer "Firex" .098 in.	440	5:25	117	348	9.5	Irritating noxious fumes.
28	Val. Chem wash primer; Ceco Firehold; green Acrylic Clear Mist; 40 mils	416	2:23	132	447	9.7	Char too fragile, erodes
23	Albi 107X; 144 7 mil	53	2:5	132	485	9.5	Char too fragile, erodes.
24	Albi 107X; 144 9 mil	61	1:36	132	207	9.9	Char too fragile, erodes.
27	Val. Chem wash primer Firehold 10; 9 mil	35	2:18	137	177	9.7	Coating cracked and eroded.

TABLE XI. (Continued)

Panel No.	Panel Description	Wt. Mtl. on Panel (gm)	Time to Burnthrough (min:sec)	Max. Encl. Air Temp. (°C)	Max. Panel Temp. (°C)	Heat Flux (Btu/sq ft sec)	Observations
28A	Val. Chem wash primer; Firehold 10; Acrylic Clear Mist; 9 mil	41	2:23	132	-	-	Coating cracked and eroded.
57	N. A. Rockwell Laticote	-	2:54	132	-	-	Coating inside, acrid smoke.
58	Laticote .040"	-	0:54	103	-	-	Irritating fumes, coating cracked allowing flame penetration.
59	N. A. Rockwell Larodyne 1/8"	382	11:39	197	219*	9.5	Strong char, some smoke at 10 min.
60	N. A. Rockwell Larodyne 1/4"	383	3:30	59	-	9.7	Coating on inside, much smoke, coating cracked.
52	Pfizer "Firex" .045"	183	3:00	127	485	9.5	Acrid smoke, not suitable.
103	Military; Olive Drab; coated aluminum	-	0:18	59	79	10	Rapid burnthrough.
73	F. R. Polyester on aluminum	98	1:54	-	-	-	Little improvement.
76	Avco Flamarest .010"	64	1:32	-	-	-	No better than other intumescent paints.

*Thermocouple disconnected

TABLE XII. RESULTS OF FURNACE TESTS ON ORGANIC, INORGANIC AND COMPOSITE INSULATIONS

Panel No.	Panel Description	Wt. Mtl on Panel (gm)	Time to Burnthrough (min:sec)	Max. Box Air Temp. (°C)	Max. Panel Temp. (°C)	Heat Flux (Btu/sq ft sec)	Observations
35	1" Scott 2-Pyrell foam	280	7:51	88	187	9.7	Thick acrid smoke, not suitable.
34	1" Scott 4-Pyrell foam	497	4:30	-	-	-	Thick acrid smoke, not suitable.
32	1" 6-Pyrell foam	712	5:42	-	-	-	Thick acrid smoke, not suitable
25	2-1/4" Uncompressed Pyrell	370	4:15	100	331	9.5	Foam burned, irritating smoke, not suitable.
63	2" Witco ICU foam	276	5:06	64	480	9.6	Irritating smoke in box comes and goes, potentially useful.
66	2.5" Witco ICU foam	303	8:30	50	329	9.7	Irritating smoke in box comes and goes, potentially useful.
46	1/2" Johns-Manville Microquartz and uncompressed Scott Pyrell (2-1/2") foam inside	594	11:48	107	154	9.5	Foam pyrolizes but does not burn, tarry residue in box, irritating smoke, burns through to microquartz only.
48	1/2" Microquartz, Microquartz, 4-Pyrell foam inside	682	6:00	71	-	9.2	Foam pyrolizes as above, burns through to microquartz only.
61	Val. Chem-Firehold 10 Paint-outside 2" Witco ICU foam inside	254	6:55	127	197	10.5	Like panel No. 63, may be useful.
66	As above with 2.5" foam	307	9:52	107	441	10.1	Like panel No. 63, may be useful.
38	Val. Chem, Firehold paint with 2" Methane foam	269	2:18	98	485	9.7	Burns easily, not as good as No. 61 or 66.
67	As above with foam glass fiber (1/8") filled	354	2:54	182	485	9.7	Burns easily, not as good as No. 61 or 66.
69	Uniroyal ICU foam 1"	197	2:36	50	443	9.5	Burns easily with acrid smoke, not as good as No. 61 or 66.
70	Urea-formaldehyde foam -2"	260	4:18	152	-	9.5	"Melts" away, nothing left, not suitable.
71	Aluminum Base, Fire Plate, 1-1/2" Witco Foam	-	10:00	-	-	-	No burnthrough, good protection from vapor and fire.
72	Aluminum, 1" Uniroyal foam, polyester, glass cloth interior	580	3:00	40	137	10.1	Foam burned, gases penetrated, ineffective sealing.

TABLE XII. (Continued)

Panel No.	Panel Description	Wt. Mtl. on Panel (gm)	Time To Burnthrough (min:sec)	Max. Box Air Temp. (°C)	Max. Panel Temp. (°C)	Heat Flux (Btu/sq ft sec)	Observations
62	9 mil Firehold 10 with 2" Witco ICU foam	276	8:00	334	50	9.7	No burnthrough, very good protection, some tar and vapors.
77	12 mils AVCO Flamarest	-	2:14	-	-	9.3	Like No. 76.
64	Aluminum, Fire Plate, 2" Witco foam	573	9:54	471	54	10.7	No burnthrough, fire protection from vapor and heat, excellent potential.
79	Aluminum, Fire Plate, ." NASA-AMES ICU foam	593	10:00	> 485	91	9.7	No burnthrough, fire protection from vapor and heat, excellent potential.
80	Aluminum, 1-1/2" AMES foam, Fire Plate	720	7:00	88	40	10.5	No burnthrough, fire protection from vapor and heat, excellent potential.
81	Aluminum, 1-1/2" AMES foam, Fire Plate, 1-1/2" AMES foam	1158	12:00	485	57	9.9	No burnthrough, fire protection, may be too heavy.
82	Aluminum, 2" Witco IW foam, Fire Plate	936	9:00	64	83	10.1	No burnthrough, fire protection, excellent potential.
83	3/4" Larodyne, BASF Fire Plate	1250	8:00	98	50	10.5	Heavy smoke.
85	Aluminum, Fire Plate, 1" Dynaflex (Johns-Manville)	729	7:00	64	74	9.2	No burnthrough, fire protection, excellent potential.
84	Aluminum, 2" NASA ICU foam, Glass epoxy inner seal coat	744	10:00	64	190	9.7	No burnthrough, fire protection, excellent potential.
87	Aluminum, 1" Dynaflex, Fire Plate	815	10:00	81	98	10.3	No burnthrough, fire protection, excellent potential.
88	Aluminum, 2" Witco foam sealed with epoxy glass	629	3:00	48	190	10.3	Foam collapsed or blew out.
86	Aluminum, [illegible] Dynaflex	307	10:00	117	348	9.7	No burnthrough, good protection if supported, excellent potential.
104	BASF Fire Plate	-	10:00	-	-	9.5	Expanded, but no burnthrough, excellent fire barrier.

TABLE XIII. RESULTS OF FURNACE TESTS ON BOX PANELS SIMULATING PRESENCE OF WIRING AND TUBING

Panel No.	Panel Description	Time to Burnthrough (min:sec)	Heat Flux (Btu/ft^2 sec)	Observations
B-1	Aluminum, AMES foam, Fire Plate	10:00	9.7	No penetration, Fire Plate cool.
B-2	Aluminum, air space, Fire Plate	10:00	10.0	Fire Plate intumesced at 5 min.
B-3	Aluminum, Dynaflex, Fire Plate	10:00	9.7	Good system.
B-4	Aluminum, Dynaflex, Simulated Tubing	8:00	9.7	Lower Dynaflex fell out, good system.
B-5	Aluminum, 2" Witco, Fire Plate	10:00	9.6	Good protection.
B-6	1/8" Plexiglas sealed in Ames foam. Acoustic quilt over window	4:00	9.7	Quilt burned at 4 min.
B-7	Aluminum, AMES foam, Tubing, Dynaflex, Fire Plate	10:00	9.7	Good system for wiring, tubing, etc.
B-8	Like box B-1 with Fire Plate joint	10:00	9.8	No vapor penetration, good system.

TABLE XIV. RESULTS OF WINDOW MATERIALS TEST PROGRAM

Panel No.	Panel Description	Time For Burnthrough (min/sec)	Heat Flux (Btu/ ft^2sec)	Observations
89	1/8" Plexiglas	1:09	10.5	Bottom ignites and burns through until structure melts, sags and eventually fails.
90	1/4" Plexiglas	1:48	10.5	"
91	1/2" Acrylite	2:48	10.6	"
92	3/4" Plexiglas	5:36	10.7	"
93	1/8" Plexiglas with 2 ml S.Kellog intum. varnish	0:58	9.5	No noticeable effect of varnish, as above.
94	1/8" Plexiglas with 2 ml S. Kellog intum. varnish	0:57	9.7	"
95	1/8" Plexiglas	0:58	9.7	No varnish - No Change
96	1/8" Plexiglas	0:52	9.6	No varnish - No Change

TABLE XIV - (Continued)

Panel No.	Panel Description	Time For Burnthrough (min:sec)	Heat Flux (Btu/ ft^2sec)	Observations
97	1/8" Merlon Polycarbonate	0:52	9.4	Burns like Plexiglas
98	1/2" Plexiglas	3:00	9.6	Burns like Plexiglas
99	1/8" Polycarbonate	0:48	9.5	Burns like Plexiglas
100	1/8" Polycarbonate, 1/4" space, 1/8" Polycarbonate	1:12	9.6	1st burnthrough-44 sec; burns like others
101	As above with space filled with aqueous (shaving) foam	1:42	10	Little improvement
74	1/8" Plexiglas with F.R. polyester finish	1:4	9.7	No improvement
75	Two 1/8" Plexiglas faces solvent welded to copper screen	2:18	9.0	Little improvement; copper did not melt; top layer burns
102	1/8" Abcite coated Plexiglas	1:12	9.5	Burns but kept from collapsing as quick

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Arthur D. Little, Inc. 20 Acorn Park Cambridge, Massachusetts	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
INVESTIGATION AND EVALUATION OF NONFLAMMABLE, FIRE-RETARDANT MATERIALS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

5. AUTHOR(S) (First name, middle initial, last name)
Sami Atallah
Henry L. Buccigross

6. REPORT DATE November 1972	7a. TOTAL NO. OF PAGES 93	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. DAAJ02-71-C-0042 b. PROJECT NO. 1F162203A529 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAMRDL Technical Report 72-52 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ADL-73588	

10. DISTRIBUTION STATEMENT
Distribution limited to U.S. Government agencies only; test and evaluation; November 1972. Other requests for this document must be referred to the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA 23604.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Eustis Directorate US Army Air Mobility R&D Laboratory Fort Eustis, VA 23604

13. ABSTRACT

A comprehensive survey was made of present materials technology. A number of materials and composites were selected and tested in a specially designed furnace capable of providing a thermal flux equivalent to that encountered in JP-4 fires. Final candidate wall systems were compared for protection effectiveness, cost, and weight penalty. Various combinations of isocyanurate foams, sodium silicate hydrate panels, a mineral insulation and intumescent mastic paints were then applied to the walls of two crash-damaged helicopters (UH-1D and CH-47) and exposed to full-scale fires simulating in-flight and postcrash fires. The helicopters were fully instrumented to measure temperature, heat flux, smoke density and toxic gases.

The results of the in-flight simulation tests indicated that it should be possible to protect the habitable compartment against a fire occurring in an adjacent compartment resulting from a fuel or hydraulic oil line leak. Sodium silicate hydrate panels placed on the fire side appeared to give the best performance.

The large-scale tests indicated that total wall protection of existing helicopters against postcrash fires is not feasible and should not be pursued any further because of cost, unreliability, and lack of assurance that the walls will maintain their integrity in a crash.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Postcrash fires						
Fire-resistant materials						
In-flight fires						
Helicopter fires						
Intumescent materials						
Isocyanurate foams						

END - 2 - 73